SPECIAL 25TH ANNIVERSARY COLLECTOR'S EDITION

OF HUBBLE SPACE TELESCOPE

The man behind Hubble's "Pillars" p. 26

APRIL 2015

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- Top science discoveries p. 28
- Space missions that saved the telescope p. 44
- How Hubble changed the world p. 50

28 BEST IMAGES FROM HUBBLE p. 56

To celebrate 25 years of discovery, the Hubble Space Telescope used its latest camera to capture this image of the Eagle Nebula, the subject of a famous 1995 photo dubbed the "Pillars of Creation."

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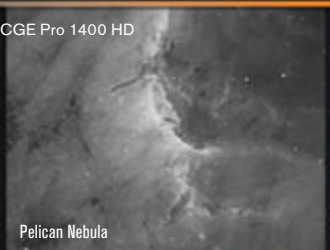
M57


Pelican Nebula


M51


The Moon


NGC 6946

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NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

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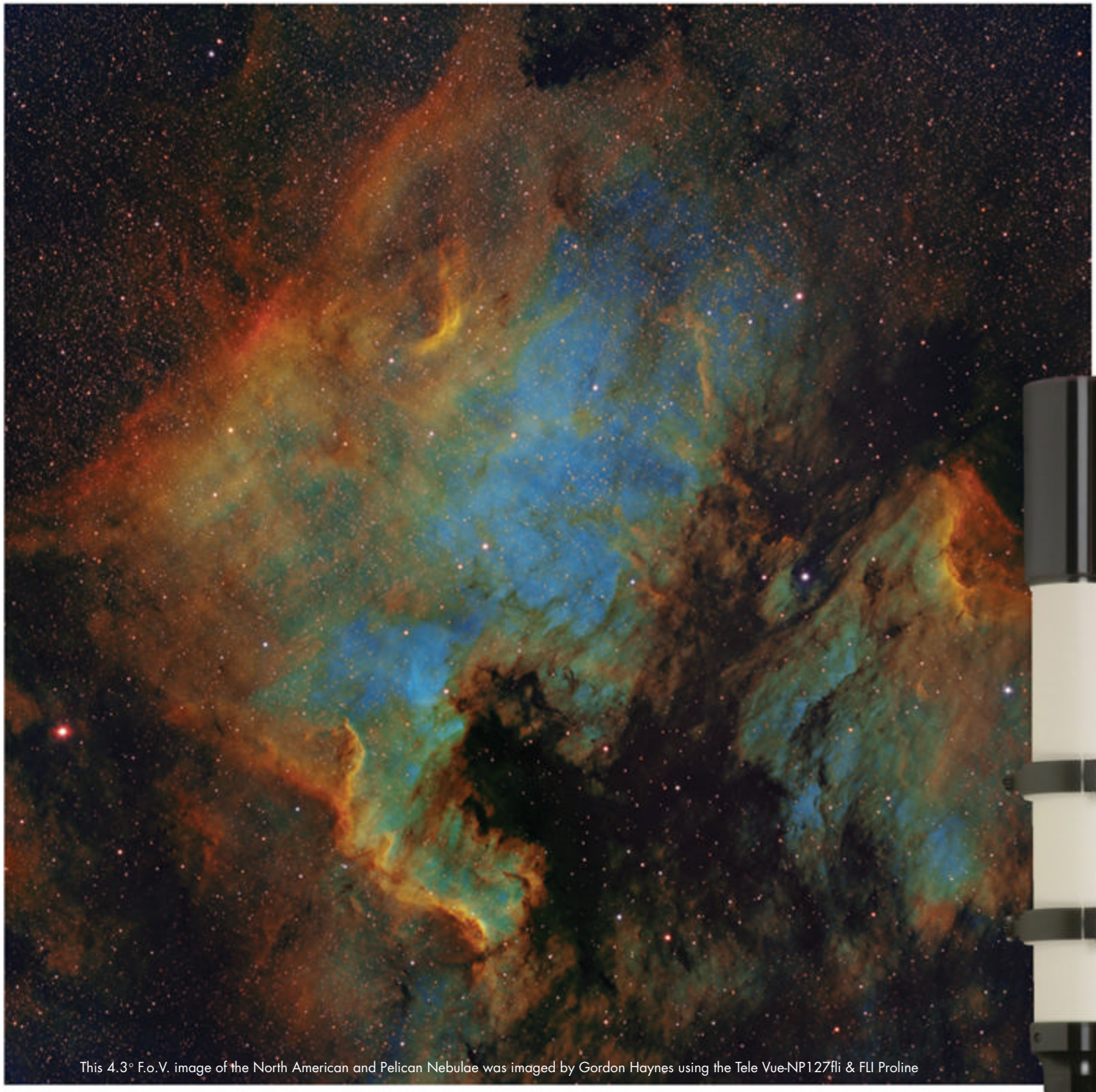


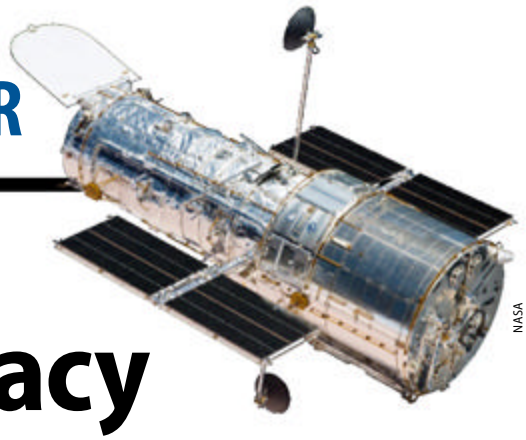
This 4.3° F.o.V. image of the North American and Pelican Nebulae was imaged by Gordon Haynes using the Tele Vue-NP127fli & FLI Proline

"Truly Plug and Play!"

Astro-imaging still isn't "point & shoot," but as Gordon says, it is finally "plug & play." "I've never had such an easy to set up and use, trouble-free imaging set up, not to mention the quality of the images! With my other scopes I'd have to interrupt sessions to adjust focus, not with the NP127fli. It simply allows more quality data gathering time. I would go as far as saying it is, without doubt, the best widefield astrograph available." The Tele Vue-NP127fli marries its flat-field, f/5.3 optics with FLI's Atlas Focuser, Centerline Filter Wheel, and Proline series cameras to create a system that simply locks together rigid, square and properly spaced. Engineered as a system, there is nothing to figure out, source, or tweak. The work is done, just go image! See more images and learn about the unique features of the NP127fli at Tele Vue.com

FROM THE **EDITOR**

BY DAVID J. EICHER



NASA

Hubble's deep legacy

Twenty-five years ago, NASA launched what promised to be the world's greatest astronomical instrument, the Hubble Space Telescope. And then, shocked and stunned when they found the optics to be flawed, engineers devised a way to fit Hubble with corrective lenses, transforming it into a machine that has rewritten our understanding of the cosmos.

This special issue examines the legacy of the instrument that, in a span of 25 years, has contributed more revolutionary observations than any telescope that preceded it. It's fitting that a quarter-century of groundbreaking science gives way to an examination of Hubble's triumphs. Our package delivers some pretty good stuff. Astronomer Mario Livio writes about the greatest scientific discoveries made using Hubble. Science writer Ben Evans details the five servicing missions that repaired and then kept Hubble going. Contributing Editor Liz Kruesi reveals the ways in which the telescope changed our culture forever. And Senior Editor Richard Talcott delivers a portfolio of Hubble's greatest images.

We also have a special online package built around a Hubble story I wrote, "How the Hubble Space Telescope changed the cosmos," with interactive graphics, slide shows, videos, and more, and you can see it at www.Astronomy.com/Hubble25.

With the launch of the James Webb Space Telescope, in some senses a successor to Hubble, looming on the horizon, it's a fitting time to look back. Hubble has at least several years left, but if not captured in orbit or serviced again, it will reenter the atmosphere, breaking apart and falling back to Earth.

The astronomer who gave Hubble its name, Edwin Powell Hubble, was born in Missouri in 1889. Growing up in Illinois, Hubble attended the University of Chicago before becoming a Rhodes scholar. The decade of the 1920s saw Hubble's biggest scientific achievements. Discovering a Cepheid variable star in the "spiral nebula" M31, now known as the Andromeda Galaxy, Hubble found evidence that the universe is larger than just the Milky Way Galaxy and defined the nature of galaxies.

On a staff note, please help me welcome our newest associate editor, Korey Haynes. She comes to *Astronomy* magazine fresh from an astronomy Ph.D. program at George Mason University in Virginia. Haynes spent most of her time in grad school at NASA's Goddard Space Flight Center, studying exoplanet atmospheres and looking for water on alien worlds. In addition to research, she was a writer for Astrobites, a blog that posts daily summaries of astronomy journal articles, and she also enjoyed volunteering at the Smithsonian's National Air and Space Museum with their Public Observatory Program.

Korey Haynes. WILLIAM ZUBACK

We're delighted to have Haynes join the staff, and look for her many contributions in upcoming issues.

Yours truly,

David J. Eicher
Editor

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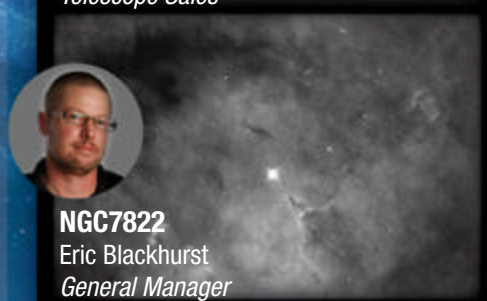

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EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

HOT BYTES >>

TRENDING TO THE TOP

MARS BOUND
Engineers at Lockheed Martin have started work on NASA's next Mars lander, InSight, which is set to launch in 2016.

GROUND GAME
For the first time, scientists detected a super-Earth passing in front of a Sun-like star using a ground-based telescope.

COSMIC CASH
A group of physicists got a share of the $3 million Breakthrough Prize in Fundamental Physics for their role in finding the accelerating universe.

SNAPSHOT

How the Moon formed

Planetary scientists believe the Moon resulted from a giant whack Earth experienced from a now-gone planetesimal, Theia.

NASA (ASTRONAUT JIM IRWIN); NASA/JPL-CALTECH (MARS BOUND); NASA AMES/JPL-CALTECH (GROUND GAME); HIGH-Z SUPERNOVA SEARCH TEAM/HST/NASA (COSMIC CASH)

Astronaut Jim Irwin salutes the U.S. flag during the Apollo 15 mission in 1971.

When we walk outside at night and look skyward, it's usually the Moon, our planet's natural satellite, that first catches our eye. The fifth-largest moon in the solar system, the Moon is one of the largest in relation to its parent body.

Called the Giant Impact Hypothesis, the accepted story of the Moon's formation suggests that 4.6 billion years ago, two planets floated in the space now occupied by the Earth-Moon system. Proto-Earth had 50 to 90 percent of its current size and mass, and a Mars-sized planet also existed, one that astronomers now call Theia (in Greek mythology, mother of the Moon goddess Selene).

Planetary scientists believe some 4.53 billion years ago, Theia struck Earth, creating a short-lived ring of debris that accreted into the Moon. The majority of Theia's mass accreted into Earth's mantle. The evidence for this scenario comes from Apollo rock samples, which contain nearly identical oxygen isotopes as those found in Earth rocks. But the story doesn't end there. Where did Theia go? You're standing on it.

— David J. Eicher

A party of fireflies

The southern constellation Carina holds some of the Milky Way's most spectacular star clusters. Case in point: NGC 3532, also known as the Firefly Party Cluster and Wishing Well Cluster. Its hottest stars glow with a characteristic blue color, while the cooler red giants appear bright orange. This 300-million-year-old cluster lies some 1,300 light-years from Earth. Astronomers captured this image through the European Southern Observatory's 2.2-meter telescope at La Silla in Chile. NGC 3532 is an appropriate subject on the 25th anniversary of the Hubble Space Telescope's April 1990 deployment because it was the orbiting observatory's first target. ESO/G. BECCARI

STRANGE**UNIVERSE**

BY BOB BERMAN

Dark vs. super dark

The difference between good and outstanding skies.

Lecturing takes me to star parties around the U.S. It's fun to see what excites backyard astronomers, and I feel honored to look through home-built telescopes. Yet interestingly, many of these gatherings are held under skies that are good — but not excellent.

This isn't a criticism. In three northeastern states, the most rural possible location is still within 30 miles (50 kilometers) of a city, producing bright glows in multiple directions. This is a central issue and battle cry for organizations like the International Dark-Sky Association, which tirelessly tries to limit waste lighting and unshielded yard lights.

Since I also lead annual overseas trips to perfect sites in deserts and such, I'm keenly aware of the dark skies issue, to which we can all relate. Strangely enough, in all these years, it's never been this column's main topic. But it now comes vividly to mind because of something that happened last night.

It was midnight, and I couldn't sleep, so I walked out to the meadow behind my house in a bathrobe and bare feet. The cold dewy grass was uncomfortable, but the moonless sky erased all body-awareness. Normally my rural area has good — but not superb — skies, yet something odd unfolded last night. Maybe it was the extraordinarily dry air. In any case, I was given a reminder of the dramatic difference between skies that are good and those that are *outstanding*.

Outstanding conditions provide an unusual experience. A strange one, truth be told. The firmament becomes so amazing — and I'm talking naked-eye — that it's worth time and expense to travel to experience it. We all know where such conditions may be found. Southern Arizona's Organ Pipe Cactus National Monument. The western states far from any town. The White Mountains of New Hampshire. Upstate New York's Adirondacks. I'd love to hear about your favorites.

Outside the U.S., many abound. Chile's northern half. Australia's Outback. The Sahara. The Persian desert southeast of Isfahan — alas, not a good travel idea these days, which is a shame because the Iranians generally like Americans and love astronomy. Here's a quick guide to what happens.

OUTSTANDING CONDITIONS PROVIDE AN UNUSUAL EXPERIENCE.

In poor urban skies, the Little Dipper only has two stars, maybe three if you can glimpse 3rd-magnitude Gamma (γ) Ursae Minoris.

In the near-city suburbs, about 130 stars appear across the sky at any given time, but there's no sign of the Milky Way.

In the farther-out suburbs, the Milky Way appears dimly. The Little Dipper has five or six stars.

In good rural regions, the Little Dipper displays all seven stars and the Milky Way is clear, its rifts showing conspicuously. The Andromeda Galaxy (M31) is obvious.

In very good rural skies, Orion's Belt is embedded in innumerable faint stars, the Milky Way is the most prominent feature of the heavens, and the Hercules globular M13 is steady. It doesn't merely come and go.

Now here's the difference as we jump up to outstanding skies. It's not subtle. In such conditions, constellations are initially confusing because so many stars pepper the scenery. The Milky Way "pops" and totally dominates the sky dome. It casts shadows. It does not have rifts or splits. Instead, intricate inky nebulae become the night's most prominent feature. Black crablike tentacles of abstract art — numerous filaments and sharp-edged blotches — form distinct cameos in front of the brilliant Milky Way. These ebony structures, I rediscovered last night, are so detailed and 3-D-seeming, they're the most in-your-face aspect of the night.

If Andromeda is up, the large round Pinwheel Galaxy (M33) dimly comes and goes in its vicinity. Fourteen Pleiads can be counted, though three may blink in and out. This is the sky nature designed. It is far superior to the view astronauts get in space. Up there, stars are dim because of the four thick glass layers in space station portholes, while spacewalkers must peer through visors of polycarbonate plastic.

But these premier earthly skies are not truly black. Air glow, caused mostly by solar ultraviolet, is always present. It bathes the unpolluted countryside with five times more light than all the stars combined. It looks brightest about 10° above the horizon. Unless you're under a canopy of trees (and what would be the point of that?), it lets you always see well enough not to stub toes, once eyes adapt to the dark.

Ah, what wonder! It's evocative of whatever got us hooked on astronomy in the beginning. It still awaits. True, these places are often farther away than in the old days. They usually entail time and expense. But not last night, when I got a gift. And who do I thank? Insomnia?

It must be insomnia.

Contact me about my strange universe by visiting **http://skymanbob.com.**

FROM OUR INBOX

Educating our youth

While I always enjoy *Astronomy* magazine, the opening pages of the October issue, in particular, had an exceptionally welcome effect on me. "Separating fact and fiction" (p. 6) by Editor David J. Eicher was a genuine piece of visionary thinking!

In my view, Eicher nailed a major dilemma of our modern culture and the goal toward which we should, and can, aspire. We do live in a society where "we are immersed in a constant stream of entertainment" and where both the younger and older generations celebrate "the trivial … not caring for the meaningful," as he aptly puts it. But, indeed, we can overcome these tendencies by educating our youth to focus their energies on realizing "where we are and why we are here."

Eicher strikes a resonating chord by challenging us to call forth our human potential and liberate ourselves to contribute to a "great forward-moving civilization of the future." These musings bring to mind a piece of wisdom reaching us from over a century ago from the Orient, the words of Bahá'u'lláh (1817–1892): "All men have been created to carry forward an ever-advancing civilization." **— Partow Izadi,** Lapland, Finland

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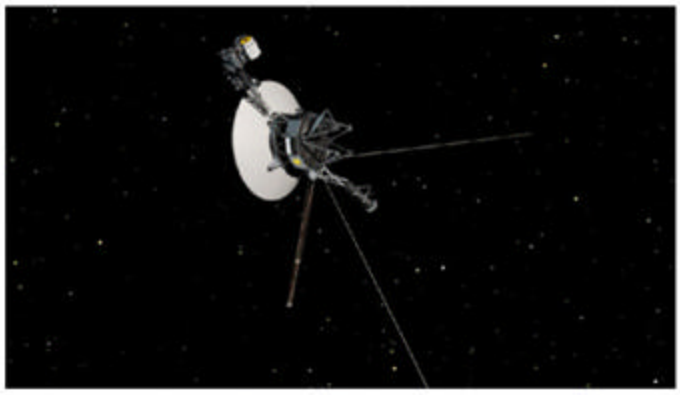
MASSIVE MERGER. Astronomers believe the massive stars in the binary MY Camelopardalis are orbiting so close to each other that they will soon merge into one massive sun. The find forwards a theory that the largest stars form this way.



TSUNAMI SIGNAL. As of November, Voyager 1, illustrated here, is still feeling the effects of a large shock wave that it originally detected last February. NASA/JPL-CALTECH

VOYAGER 1 EXPERIENCES LONG-LASTING SHOCK WAVE

When the Voyager 1 spacecraft passed the realm of the planets and headed toward interstellar space, scientists couldn't be sure what to expect. After all, this was a new frontier of space exploration. And according to the University of Iowa's Don Gurnett, who presented new Voyager data December 15 at the American Geophysical Union meeting in San Francisco, the interstellar medium the spacecraft officially entered in 2012 has had its surprises.

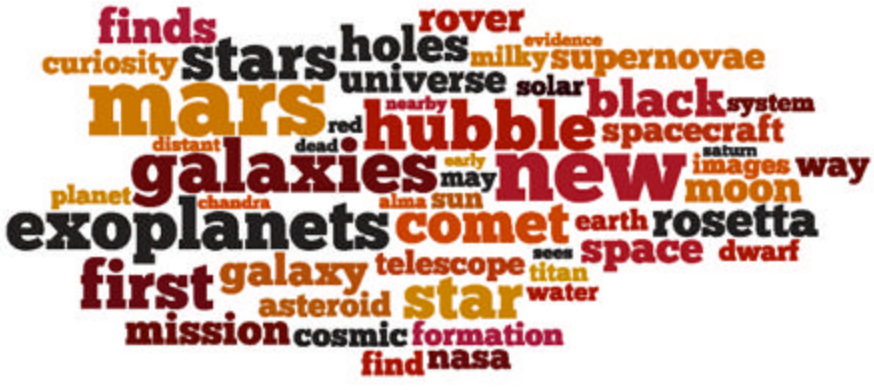
Since October 2012, Voyager 1 has experienced three "tsunami waves." Such shock waves occur when a wave of pressure from a coronal mass ejection — a huge explosion of plasma from the Sun — runs into the interstellar plasma that exists between the stars. The first two tsunami waves Voyager detected lasted around a month each, but the spacecraft was still feeling the effects of one that began in February 2014 as of November. In that time, Voyager traveled 250 million miles (400 million kilometers).

"Most people would have thought the interstellar medium would have been smooth and quiet," Gurnett said in December. "But these shock waves seem to be more common than we thought." In addition, scientists are still not sure what the length of the most recent tsunami wave means. **— Karri Ferron**

THE "NEWSIEST" ASTRONOMY WORDS IN 2014

The Rosetta mission to Comet 67P appeared in 25 news stories, while the Curiosity Mars rover appeared in 16.

FAST FACT



FREQUENT FINDS. In the January issue, *Astronomy* counted down the biggest news stories of 2014, but what about the topics that most frequently appeared in the year's headlines? This diagram shows the 100 most popular words in Astronomy.com news headlines in 2014, with each word's size proportional to the number of times it appeared. *ASTRONOMY*: CHUCK BRAASCH AND KARRI FERRON

BRIEFCASE

TITAN'S DUNES CREEP SLOWLY

In two independent papers published online December 8 in *Nature* and *Nature Geoscience*, scientists announced that surprising winds sculpt the dunes of Saturn's moon Titan. Most of Titan's winds blow from the east, but only the stronger, more intermittent westerly winds can heave the dunes' massive weight. Scientists found that the dunes morph slowly over timescales of around 3,000 Saturn years (about 88,000 Earth years), meaning the process relates to long-term climate change, far beyond the cycles of tides or seasons.

PLANCK SHEDS LIGHT ON DARK MATTER

Scientists have finished analyzing data from the European Space Agency's Planck satellite, which observed between 2009 and 2013. The team announced December 1 that they are now able to rule out an entire class of dark matter candidates. These particular candidates are known for dark matter-antimatter annihilation, which would manifest observable cosmic rays. While other experiments have found cosmic-ray excesses they tentatively attributed to dark matter annihilation, Planck disagrees and attributes these to less exotic sources such as pulsars.

NASA GETS BUDGET BOOST

Congress raised NASA's budget 2 percent December 9, to $18 billion. The science mission directorate in particular received an almost hundred million dollar increase, with planetary science getting a big boost. Earth science funding remained flat, while human spaceflight received strong support both for private companies like SpaceX and NASA's own Space Launch System rocket and Orion crew capsule. Overturning the White House's suggested cancellation, Congress also decided to continue funding SOFIA, NASA's infrared telescope that flies in its own modified Boeing 747. **— Korey Haynes**

25 years ago in *Astronomy*

In the April 1990 issue of *Astronomy*, spacecraft Galileo had recently blasted off from Earth and was five years away from its Jupiter rendezvous. Joel Harris spoke with project scientists about the mission's potential to revolutionize our understanding of Jupiter. Worry abounded for all the steps yet to come, but Galileo lived a long and scientifically prosperous life around Jupiter until 2003, when it plunged nobly into the atmosphere to its demise.

10 years ago in *Astronomy*

In April 2005, Huygens had recently touched down on the surface of Titan. Senior Editor Richard Talcott spoke with mission scientists who shared their excitement and relief over the probe's successful landing. Its partner spacecraft, Cassini, spent six months orbiting Saturn before dropping Huygens down to the surface of Saturn's largest moon, where it discovered methane springs and rivers. **— K. H.**

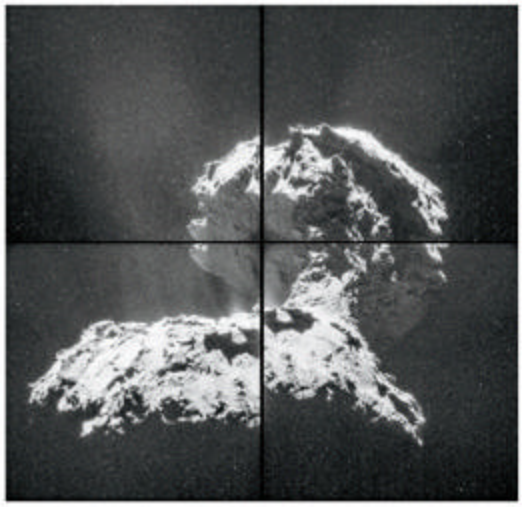
DUST SURVEY. Astronomers used the twin Keck Telescopes in Hawaii to survey dust around 50 mature Sun-like star systems for several years as a step toward finding planets that might harbor life.

Rosetta refreshes debate on Earth's water

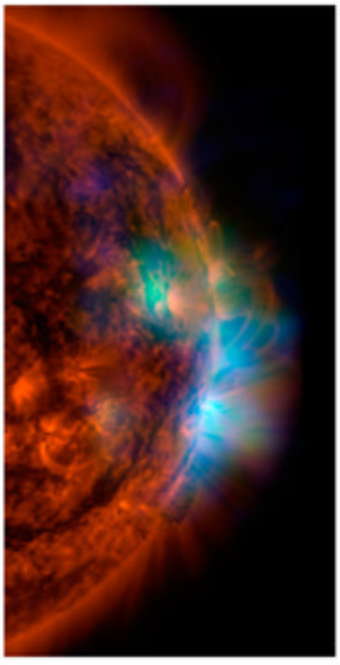
The European Space Agency announced December 10 that its Rosetta spacecraft had measured water vapor from Comet 67P/Churyumov-Gerasimenko and found that it is much heavier — by a factor of three — than the water in Earth's oceans. The "heaviness" of water is a measurement of how many of the H's in H_2O have a proton and a neutron (deuterium) compared to just a proton (normal hydrogen). Earth's water has a well-established deuterium/hydrogen (D/H) ratio.

Scientists have long suspected that Earth's water might have been delivered from space via asteroids or comets, so they study these objects' water compositions to find which populations have D/H ratios that match our planet's. So far, few comets provide good matches, and Comet 67P just struck out as well.

But maybe we don't need comets anyway: Here on Earth, researchers from Ohio State University reported December 17 at the American Geophysical Union meeting in San Francisco that our planet might have made its own water. Scientists have known for a long time that Earth's mantle is a potentially huge reservoir of water, but the idea that Earth could mine that reservoir through plate tectonics and bring water to the surface in any substantial amount is a new idea. — **K. H.**



WATER STRIKE OUT. Dust and gas can be seen outflowing from Comet 67P, but the water vapor Rosetta measured doesn't fit the makeup of Earth's water. ESA/ROSETTA/NAVCAM, CC BY-SA IGO 3.0



NASA/JPL-CALTECH/GSFC

Deep-space telescope looks closer to home

SIZZLING SUN. NASA's Nuclear Spectroscopic Telescope Array (NuSTAR), a satellite designed to detect hard X-rays in distant objects, turned its eye toward the Sun for the first time, capturing the most sensitive picture of our star in high-energy X-rays. The new image, released December 22, shows NuSTAR's X-ray data overlaid on a photo taken by NASA's Solar Dynamics Observatory. In the future, NuSTAR will seek out the Sun's hypothesized nanoflares, smaller versions of our star's massive eruptions of charged particles. — **K. F.**

CANNIBAL GALAXY. NGC 3226 can be seen here with its smaller companion, NGC 3227. The swirls of gas and dust around them are signs that NGC 3226 likely collided with and consumed a third galaxy sometime in the recent past. NASA/CFHT/NRAO/JPL-CALTECH/DUC/CUILLANDRE

Shutting down star factories

In separate studies published in *The Astrophysical Journal*, astronomers announced two galaxies that at first glance should be churning out new stars but instead are too hot to bother. The ideal stellar breeding ground has lots of cool gas that quietly collapses into baby suns. So supermassive black holes that blow the gas right out of their galaxies are known quenchers of star formation, and galaxy mergers that dump new fuel into old galaxies are known harbingers of stellar population booms.

NGC 1266 has a modest central black hole and plenty of gas, but this gas is so dense that the black hole is merely stirring it madly. The jets streaming from the black hole aren't powerful enough to eject the fuel from the system, but new results from the Atacama Large Millimeter/submillimeter Array show that the roiling gas is too turbulent for star formation.

NGC 3226 is the site of a recent merger, but in this case as well, the gas is too hot to permit star formation. It took the combined work of the European Space Agency's Herschel Space Observatory and NASA's Spitzer and Hubble space telescopes to tell this galaxy's story. While galaxy mergers usually incite star formation, in this case the incoming gas is crashing into and heating up in the galaxy's disk, stalling stellar baby-making.

In both cases, future star formation is likely, after NGC 1266's central black hole quiets down and NGC 3226's turbulence calms, allowing the gas to cool enough to form new stars. — **K. H.**

QUICK TAKES

AMNESIAC EXPLORER

The travel-weary Mars rover Opportunity continued to struggle through flash memory issues in December as NASA tried to reformat. Exploration continues, but data has to be sent to Earth before the craft is put to sleep at night.

STRANGE SPIRAL

Citizen scientists using Galaxy Zoo helped find a bizarre spiral galaxy shooting off large jets of subatomic particles from its core at near light-speed. Theory holds that only elliptical galaxies, formed by merging spirals, should have jets.

MIRAGE EARTHS

A new study warns of "mirage Earths," which would sit in habitable orbits close to low-mass stars, that computer simulations show can be stripped of the chance to host life by intense heat that wipes away water and atmospheres during their early formation.

MISSING ATMOSPHERE

Europa's icy plumes were not seen in data NASA's Cassini craft collected at the jovian moon, mission scientists said in December. The team found Europa's atmosphere is 40 times more tenuous than thought and its plasma originated from volcanoes on Io.

EARLY FINDS

Not long after arriving at Mars, NASA's MAVEN orbiter has found interesting clues to how the planet loses its atmosphere to space, discovering a new population of ions scientists can use to study interactions with the solar wind.

SOLAR SMASHING

An entire family of Pluto-sized objects may have been seen stirring up dust around a young Sun-like star, as the planetesimals cause smaller bodies to collide. The find pairs with models that predict gas is prevalent in the outer reaches of young solar systems.

INDIA JOINS TMT

India is now a full member in the behemoth Thirty Meter Telescope (TMT) on Mauna Kea, joining fellow Asian nations China and Japan, as well as institutions in the U.S. and Canada. Work on the massive project began in October 2014.

X-RAY HUNTER

The European Space Agency's prolific X-ray observatory, XMM-Newton, celebrated 15 years in space December 10. Its replacement, Athena, won't be launched for at least a decade. — **Eric Betz**

CROSS EXAMINATION. Scientists took a second look at Antarctic meteorite ALH84001, once thought to hold martian fossils. They unraveled a 4-billion-year journey: Volcanic birth, floods of carbonate-carrying seas, and finally Earth circa 11,000 B.C.

SPACE SCIENCE UPDATE

NEW TALES OF A WARMER, WETTER MARS

LAKE LAYERS. NASA scientists say that cross-bedding in these rocks visited by the Curiosity rover is evidence that Mars' Mount Sharp area once held a vast lake. NASA/JPL-CALTECH/MSSS

In one of the most tantalizing Mars finds to date, NASA's Curiosity rover caught methane wafting across the surface of the Red Planet. Then it was gone. And then it returned. The methane came and went three times in Curiosity's data.

NASA Jet Propulsion Laboratory scientists announced their discovery at a press conference December 16 in San Francisco and received international headlines. Methane does not mean there's life on Mars, but that is one enticing explanation. The tenfold spike in methane concentrations seen in the atmosphere around the rover were backed up by organics found in martian soil powder samples made with Curiosity's rock drill.

"This temporary increase in methane — sharply up and then back down — tells us there must be some relatively localized source," says Sushil Atreya of the University of Michigan, Ann Arbor, who works on the Curiosity rover team. "There are many possible sources, biological or non-biological, such as interaction of water and rock."

The excitement added to a rash of Red Planet news. At the same time, astronomers announced their find that Mount Sharp — Curiosity's stomping grounds — was once a massive lake. NASA scientists say the sediments there appear to have been laid down over the course of tens of millions of years.

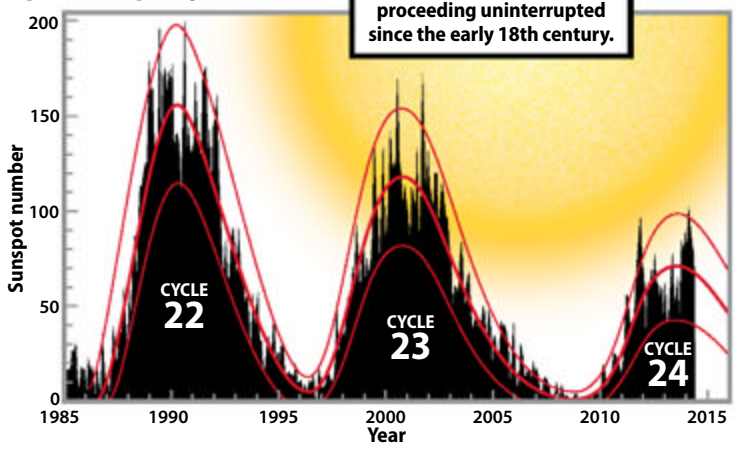
"We are making headway in solving the mystery of Mount Sharp," says Curiosity Project Scientist John Grotzinger of the California Institute of Technology in Pasadena. "Where there's now a mountain, there may have once been a series of lakes."

And as those lakes came and went, they dropped layers of sediments and left behind clues about the state of the local martian environment. As Curiosity continues its uphill climb from the lowest sedimentary layers, it will observe how the chemistry changed over time. The rover will drill often, keeping an eye out for more signs of organics. **— E. B.**

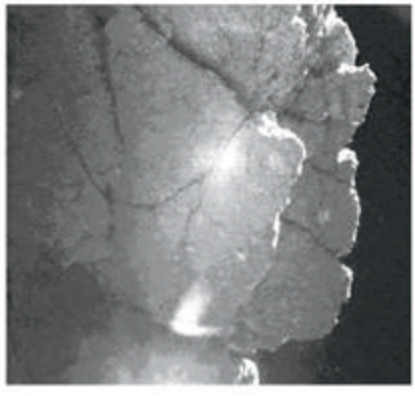
SOLAR ACTIVITY STARTS TO WANE

The solar cycle currently averages about 11 years from peak to peak and has been proceeding uninterrupted since the early 18th century.

FAST FACT



DOUBLE MAX. Solar cycle 24 seems to be winding down, having reached a second and apparently final peak in November 2013. Scientists at NASA's Marshall Space Flight Center in Huntsville, Alabama, say the number of sunspots (officially the smoothed International Sunspot Number) then reached 75.4. Cycle 24's first peak delivered 66.9 sunspots in February 2012. Although many cycles show a two-humped profile, this is the first where the second peak beat the first. Still, this is the weakest sunspot maximum since cycle 14 peaked at 64 in February 1906. (The outer red curves show the expected range of the monthly sunspot numbers.) *ASTRONOMY:* RICHARD TALCOTT AND ROEN KELLY, AFTER HATHAWAY/NASA/MSFC



BUT WHERE IS HERE? Philae sent back this image of its current surroundings, dubbed "Perihelion Cliff." The white regions probably represent glare from the lander itself. ESA/ROSETTA/PHILAE/CIVA

Little lander lost

Like your mother's worst nightmare, Philae remains lying in a ditch somewhere on Comet 67P/Churyumov-Gerasimenko, and scientists are hard at work scanning through three days of photos taken by Philae's partner spacecraft, Rosetta, looking for their lander. But don't worry: Philae may reawaken when the Sun finds the instrument's solar panels in early spring.

Meanwhile, Rosetta delivers science results on the nature of cometary water (too heavy to be the source of Earth's oceans) and returns pictures of "dinosaur egg" structures. These structures may indicate the size of the solar system's building blocks from which the planets, comets, and asteroids all came. **— K. H.**

SECRETSKY

BY STEPHEN JAMES O'MEARA

Into the void

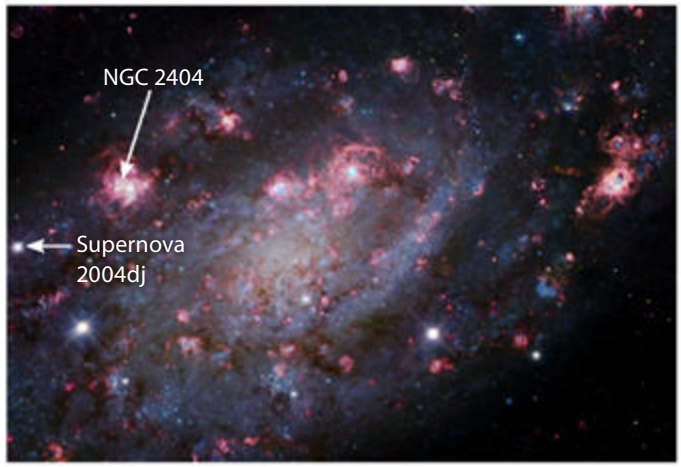
This galaxy really is lost in space.

The north celestial polar region has a significant void fairly close to the North Star, Polaris (Alpha [α] Ursae Minoris). To find it, look in the space bounded by it, Capella (Alpha Aurigae), Mirfak (Alpha Persei), and Omicron (o) Ursae Majoris (the nose of the Great Bear).

This vast emptiness tallies only three stars in the 4th-magnitude range. Nevertheless, it hosts one of the oddest and most elusive constellations, Camelopardalis the Giraffe. Despite the figure's dim appeal to the unaided eye, it contains one of the most photogenic galaxies in the northern sky: NGC 2403, the overlooked masterpiece of the Arctic void.

In images, NGC 2403 is a near twin to the Pinwheel Galaxy (M33) in Triangulum, but with pumped up visual appeal. It has two tiers of spiral arms that flaunt robust star-forming regions, each rapidly spawning massive stars that will live fast and die young in remarkable supernova explosions. The striking Hubble Space Telescope image on this page shows many of these ionized hydrogen regions bursting forth like pink cosmic fireworks. The image also includes Supernova 2004dj, which flared to magnitude 12 and shone as brightly as 200 million Suns.

In 1954, another fantastic outburst occurred in NGC 2403. Although it was classified as Supernova 1954J, recent research has shown it to be a "supernova imposter." The star did not destroy itself but survived a super-outburst similar to the "great eruption" in 1843 of Eta (η) Carinae in our Milky Way. Hubble Space Telescope images have since resolved a nebula around this outburst-surviving star that's akin to the Homunculus Nebula around Eta Carinae.



Spiral galaxy NGC 2403 is the standout object within the constellation Camelopardalis. This image shows the star-forming region NGC 2404 as well as the galaxy's most recent supernova. DATA: SUBARU TELESCOPE (NAOJ)/HUBBLE LEGACY ARCHIVE; PROCESSING: ROBERT GENDLER

In search of a giant

Although NGC 2403 lies in Camelopardalis, it is within sniffing distance (7.5° northwest) of the Great Bear's nose. The galaxy shines at magnitude 7.3 and from a dark sky is visible through 10x50 and larger binoculars.

Through a small telescope at moderate magnification, it appears as an extremely well-defined elliptical glow punctuated by two 11th-magnitude stars on either side of its amorphous, lens-shaped core. Larger telescopes may show up to about a dozen stars superimposed on the galaxy.

The arms break into several distinct petals of light, all of which display delicate irregularities — a combination of superimposed stars from the Milky Way and a plethora of star-forming regions in NGC 2403. The regions of ionized hydrogen in NGC 2403 are so exceptionally large and luminous that at least six of them rival the most massive ones in our Local Group of galaxies — namely the Tarantula Nebula (NGC 2070) in the Large Magellanic Cloud and NGC 604 in M33.

The brightest of NGC 2403's star-forming regions is NGC 2404. It appears as a tiny diffuse knot at the eastern end of the northern spiral arm. Guillaume Bigourdan at the Paris Observatory discovered it in 1886 with a 12-inch refractor. This remarkable extragalactic treasure spans 2,000 light-years, or nearly 50 times the width of the Orion Nebula (M42). While many observers today have seen it through scopes of similar size, I challenge you to observe it through as small a telescope as possible.

As always, let me know what details you see in NGC 2403 at sjomeara31@gmail.com.

COSMIC WORLD

A look at the best and the worst that astronomy and space science have to offer. **by Eric Betz**

Cold as space ← → Supernova hot

Mars or bust

NASA tests the Orion spacecraft, calling it the next step to Mars. Now they just need a lander, habitat, propulsion, water extractors, radiation shields, and hundreds of billions in cash.

Artistic license

Dr. Black Holes himself, Kip Thorne, publishes findings from his work with artists on the movie *Interstellar*. Sadly, his paper on bookshelf beings is held up in review.

Space blanket

Eager attendees line up at a Texas quilting show for a glimpse of astronaut and first-ever space quilter, Karen Nyberg, and her sewn stars. High marks for floating with scissors.

#CometLanding

ESA lands on Comet 67P and draws more adoring fans with little Philae than Kim Kardashian's simultaneous #BreakTheInternet derrière photo. Faith in humanity restored.

NASA/JPL/CORNELL (MARS OR BUST); ESO/M. KORNMESSER (ARTISTIC LICENSE); NASA (SPACE BLANKET); ESA/ATG MEDIALAB (#COMETLANDING)

FROM OUR INBOX

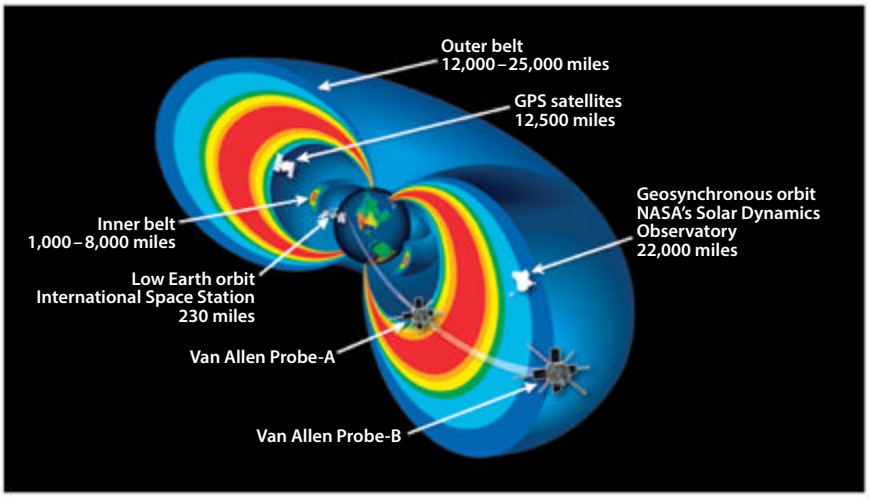
Excellent issue

I just got into the December *Astronomy* magazine and found it to be one of the best of many of the ones I have read over the years. Thank you for the sound articles based on astrophysics such as the "Five stars that could go bang," "How Gaia will map a billion stars," and others. Even my old favorite Bob Berman had a timely article (his humor lives on). Great job and solid good work! **— Edmund Anderson,** Cary, North Carolina

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara.**

MOVIN' RIGHT ALONG. The most prolific planet finder to date, NASA's Kepler spacecraft, proved it's still got what it takes in December, discovering a new world after the space agency gave the hobbled telescope a second chance.

Van Allen Belts still hold surprises



BELT BARRIER. A newly discovered barrier in the Van Allen Belts protects Earth from "killer electrons." NASA

Our planet's magnetic field holds a toroidal band of radiation in a belt around Earth. These Van Allen Belts protect us from solar eruptions, growing and shrinking as they're excited.

The find is known as the first great discovery of the space age. And despite Americans getting to space second, the discovery was ours.

But even after nearly 60 years, the belts still hold new surprises. On November 27, astronomers announced in the journal *Nature* they had found an impenetrable barrier within the belts that prevents the most energetic particles — so called "killer electrons" that can threaten astronauts and spacecraft — from reaching Earth.

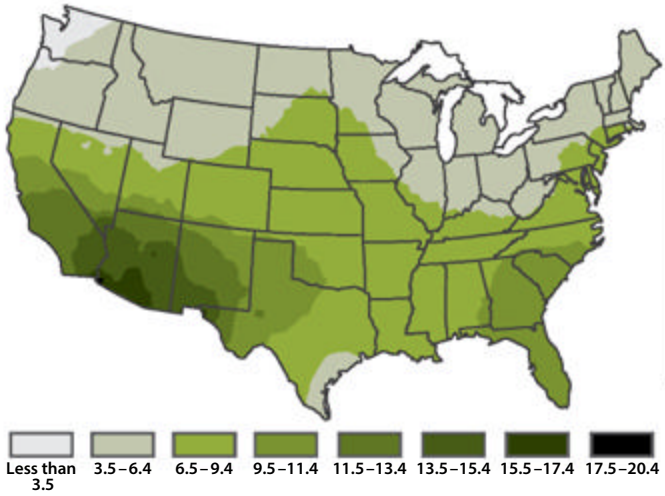
"It's almost like these electrons are running into a glass wall in space," says Daniel Baker of the University of Colorado, Boulder, who did his doctorate with the belts' discoverer, James Van Allen, and was lead author on the study.

"Somewhat like the shields created by force fields on *Star Trek* that were used to repel alien weapons, we are seeing an invisible shield blocking these electrons. It's an extremely puzzling phenomenon."

The main belts start at an altitude around 600 miles (1,000 kilometers) above Earth and can stretch to some 25,000 miles (40,000km). The particles come from the solar wind and cosmic rays. This newly discovered barrier sits at some 7,200 miles (11,600km).

And this isn't the first time the belts have offered up surprises. In 2012, NASA launched the two identical Van Allen Probe spacecraft to confirm what scientists thought they knew. At first, Baker says he figured the instruments were faulty because the data seemed so improbable. But NASA's probes had turned up a new radiation belt. "The textbooks always said two belts, and here we had three belts," Baker says. **— E. B.**

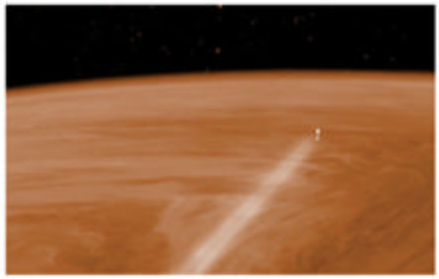
AVERAGE NUMBER OF CLEAR DAYS IN APRIL



ASTRONOMY: MICHAEL E. BAKICH AND ROEN KELLY, AFTER NOAA

FAST FACT

April's sky features two of the finest deep-sky objects: Omega Centauri (NGC 5139) and the Whirlpool Galaxy (M51).



MISSION COMPLETE. During its last months before running out of propellant, the Venus Express spacecraft dove deeper into our sister planet's atmosphere, as illustrated here. ESA/C. CARREAU

Venus Express runs out of fuel

After eight years orbiting our sister world, providing extensive data on its atmosphere and allowing scientists to make conclusions on the properties of its surface, the European Space Agency's (ESA) Venus Express probe exhausted the last of its propellant, and the mission officially ended December 17. Mission leaders initially lost contact with the satellite November 28, but they were able to re-establish limited telemetry information that ultimately led them to conclude that Venus Express used up the last bit of its propellant and was losing altitude.

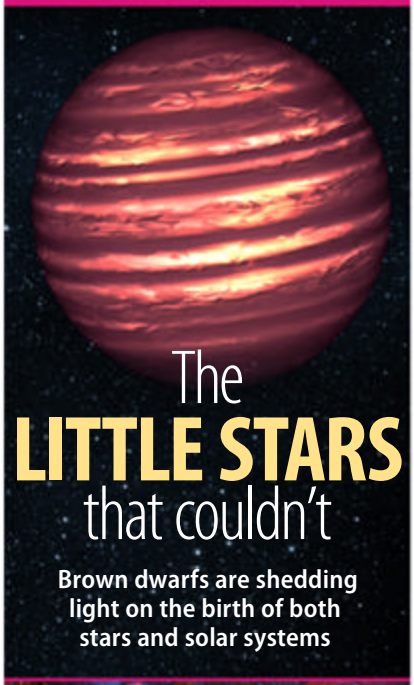
Mission scientists knew they were nearing the end in 2014, so they decided to "go out with a bang" by having Venus Express perform a complicated aerobraking campaign that brought the spacecraft as close as 80–84 miles (130–135 kilometers) above the planet's surface from mid-June to mid-July before returning to an altitude of 285 miles (460km). As the orbiter naturally would lose altitude over time and required routine thruster burns to return it higher above Venus, mission scientists decided to raise the spacecraft again in late November in order to possibly prolong the mission. But as Venus Express has no fuel gauge, they did not know such maneuvers would exhaust what little fuel was left.

"While we are sad that this mission is ended, we are nevertheless happy to reflect on the great success of Venus Express as part of ESA's planetary science program and are confident that its data will remain [an] important legacy for quite some time to come," says Martin Kessler, head of ESA Science Operations. "The mission has continued for much longer than its planned lifetime, and it will now soon go out in a blaze of glory." **— K. F.**

2 million mph (3.2 million km/h)

The speed of cold gas being ejected from the compact galaxy SDSS J0905+57 as star formation shuts down.

COMING IN OUR
NEXT ISSUE



The LITTLE STARS that couldn't

Brown dwarfs are shedding light on the birth of both stars and solar systems

A northerner's view of the southern sky

Does the Southern Hemisphere really have all the good stuff?

Budget battle

The fight to save Lick Observatory

PLUS

- Explore the Virgo Cluster
- Stars, rock 'n' roll, and the meaning of life
- Touring the Herschel Museum
- *Astronomy* tests Daystar's Quark filter

Astronomy magazine

NASA/JPL-CALTECH (BROWN DWARFS); TERRY HANCOCK/FRED HERRMANN (SOUTHERN SKY); LAURIE HATCH (LICK OBSERVATORY)

OBSERVING**BASICS**

BY GLENN CHAPLE

Rainy-day Web surfing

Astronomy.com offers lots to explore on April's cloudy nights.

April showers bring May flowers. They also bring frustration to observers kept indoors by April's ever-present cloudy nights. Outer space may be out of reach, but cyberspace isn't.

If inclement weather has you and your telescope grounded, Astronomy.com will keep you cosmically connected. There's a lot to explore, so let's get to our computers, log on, and see what we can find. We'll begin with sections accessible to anyone, regardless of subscription status.

A good place to start is "The Sky this Week," a day-by-day account of celestial happenings spanning the current 10-day period. It's one of a dozen topic selections found in the "Observing" drop-down menu at Astronomy.com. "The Sky this Week" might find us gazing wistfully at a description of what's currently going on above the clouds, but do we really want to know that we're missing a major meteor shower or rare planetary alignment? Better to think positive and look ahead to upcoming sky events we'll be able to enjoy when (fingers crossed!) skies clear.

No matter what our level of expertise, we need to pay attention to the techniques that make us successful backyard astronomers. To that end, the "Observing" section serves up an assortment of how-to articles and videos. The subsection "Get to Know the Night Sky" includes articles on "The starry sky" (a seasonal primer on star and constellation identification), "How to use a star chart" (a guide to using the StarDome map in the center of each issue of *Astronomy*), "Choose a star atlas that's right for you," and articles dedicated to urban skygazing. The "Observe the Solar System" and "Tour the Deep Sky" subsections combine basic facts about the solar system bodies with pointers on how to observe them.

A key "Observing" subsection is "Equipment Use" — a must-visit destination for anyone seeking information on astronomical equipment. Looking for guidance on purchasing that first telescope or binoculars? It's here. Want to know about accessories like eyepieces, finder scopes, or filters? "Equipment Use" has the inside scoop.

Some Web content is available only to registered users of Astronomy.com. Don't worry; registration is free — even to those who aren't *Astronomy* subscribers. You can sign up at www.Astronomy.com/register.

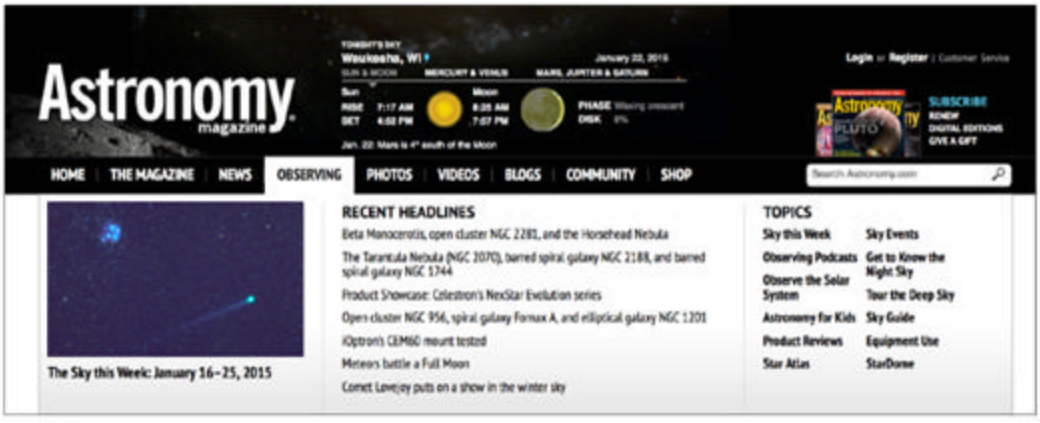
Among the benefits to being a registered user is access to Senior Editor Michael E. Bakich's "Observing Podcasts," weekly spotlights on currently visible deep-sky destinations. Last month, I stressed the importance of having a prepared list of sky objects prior to observing. A rainy evening gives us time to assemble lists for future clear nights, and "Observing Podcasts" is our go-to place to get started. We can work on the objects featured in this week's edition or scroll down to April podcasts of previous years to add even more.

There's much more to Astronomy.com's "Observing" section, but we'll move on to the "Videos" section next. Two video series of particular interest are "Observing Basics" (not my column — that comes later) and "Seasonal Observing." The former is a collection of Bakich video clips that help you get the most from your equipment. The latter includes a video of easy-to-find targets in the current season's sky, which is available to registered users, as well as other videos available exclusively to subscribers of *Astronomy* magazine (as are all Astronomy.com items accompanied by an "A+" symbol) that feature seasonal lists of deep-sky objects.

I've been writing the "Observing Basics" column for over a dozen years. If you're an *Astronomy* subscriber, you can access an archive of these articles at www.Astronomy.com/Chaple. I can't say I've covered every astronomy-related topic (it's a big universe!), but you'll find pieces devoted both to backyard astronomy techniques and easy-to-observe sky objects.

There's so much to see on Astronomy.com that we may wish for the April rains to continue for the next few evenings so we can further explore its offerings. OK, that's a stretch, but at least it gives us the option of pursuing our hobby on cloudy nights. So disparage not the rains of April, my friend! They bring not only May flowers, but also the chance to enhance our backyard astronomy experience.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: We track down the "runaway star." Clear skies!



FROM OUR INBOX

Women in astronomy

I found captivating an article in the January 2015 issue, "Where are the women in amateur astronomy?" (p. 60). As a woman, I often feel outnumbered in the field. Astronomy has always been an interest of mine, but lately it has taken center stage as my passion. I found this article particularly interesting because it spoke to me about the barriers that many women have to overcome to really be taken seriously in the field of science. I feel these barriers, and the article reassured me that I am not alone.

— Noelle Moser, Maryville, Tennessee

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple.**

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WHAT ARE WE LEARNING ABOUT GLOBULAR CLUSTER FORMATION?

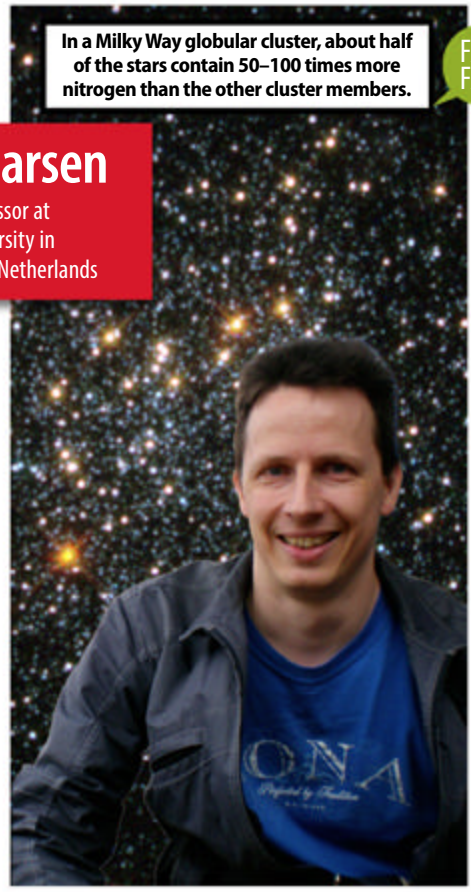
Søren Larsen
Assistant professor at Radboud University in Nijmegen, The Netherlands

The Milky Way is home to about 150 globular clusters, of which the brightest are spectacular sights when viewed through an amateur telescope. Yet it remains a mystery how exactly these massive swarms of stars formed. In particular, their chemical composition is a puzzle: In about half of the stars in a typical globular cluster, the "light elements" (up to aluminum) are found in relative amounts that are only seen in these stellar conglomerations.

The explanation favored by some is that globular clusters consist of an original "pristine" population of stars formed by normal processes and a polluted population formed out of enriched ejecta produced by the original stars. The main problem with this idea, however, is that the amount of polluted ejecta that the original stars could produce only would be a few percent of the total mass — in stark contrast to the observed 1:1 ratio. To balance the budget, a large fraction of the original stars must have been lost from the cluster. In this picture, present-day globular clusters are the remnants of systems that initially may have been at least 10 times larger!

If this is true, then the lost stars should now be "free-floating" among the field stars in their parent galaxies. However, our recent observations of globular clusters in the Fornax Dwarf Galaxy have challenged this picture. We found that the four most metal-poor clusters together account for about a quarter of all the metal-poor stars in that galaxy. Furthermore, our new observations with the Hubble Space Telescope show that the Fornax clusters display the same chemical abundance anomalies as globular clusters in the Milky Way, so the same formation scenario should apply to them. But it seems that these clusters could not have lost the required large fraction of their initial stars — there are simply not enough metal-poor stars in the Fornax Dwarf! So we need to go back to the drawing board.

FAST FACT In a Milky Way globular cluster, about half of the stars contain 50–100 times more nitrogen than the other cluster members.



COURTESY SØREN LARSEN (PORTRAIT); NASA/ESA/S. LARSEN (RADBOUD UNIVERSITY, THE NETHERLANDS) (FORNAX 2)

ASTRO**NEWS**

INSIDE EINSTEIN. Princeton University Press has made tens of thousands of original Albert Einstein documents available online free for the first time via The Digital Einstein Papers, enabling open access for all to the mind of a genius.

SPACE ATTACK. Scientists think that Earth's early atmosphere was stripped under bombardment from an onslaught of small asteroids. NASA

Asteroids stripped Earth's atmosphere

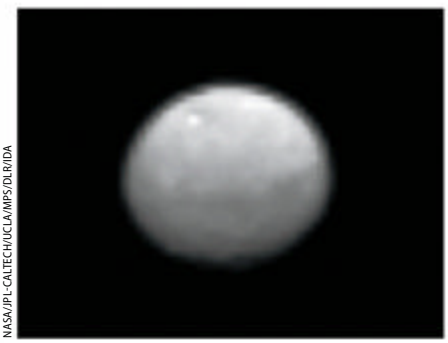
Early in its history, Earth was bombarded by a cosmic blitzkrieg of space rocks that likely stripped the fledgling world of its atmosphere, according to a paper published in the journal *Icarus* in February.

A team of researchers modeled what would happen if tens of thousands of small asteroids smashed Earth and found that all the little impacts add up to a major loss.

Whereas it would take a collision with a near-Earth-sized body to strip our planet of its atmosphere, the scientists show that each of the small impacts can be much more efficient in the damage they cause. And exactly such a period of bombardment is thought to have happened around the time the Moon formed, which was still early in Earth's history.

The astronomers think their find could help explain geochemical evidence that indicates Earth has lost its entire atmosphere at least twice in the long period since it first formed some 4 billion years ago. Their find also could be important in explaining the atmospheres of the other rocky planets, Venus and Mars. — **E. B.**

Dawn approaches Ceres for asteroid encounter



NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

DAWN APPROACHES. The Dawn spacecraft captured this better-than-Hubble shot of the dwarf planet Ceres on approach in January. By March, the craft will start orbiting the asteroid belt's largest object.

NASA's Dawn spacecraft will reach the asteroid belt's largest object, Ceres, this spring, heralding in new knowledge of the Texas-sized space rock that astronomers once called a planet. Ceres remains the largest unexplored body between Earth and Pluto.

Dawn launched in 2007 and visited asteroid Vesta for just over a year starting in 2011. Astronomers had some ideas about that dwarf planet from studying meteorites thought to have originated at Vesta.

But that's not the case for Ceres, which will be studied for the first time. Dawn is also just beginning to see the asteroid with any clarity. The navigation images NASA captured with the craft's camera in January are the first with better detail than the Hubble Space Telescope. So scientists don't even know what the world looks like. One strange feature has piqued curiosity — a large white spot (upper left of image), which was also seen in Hubble photos.

"All we can predict with confidence is that we will be surprised," says the Dawn mission's principal investigator, Christopher Russell of the University of California, Los Angeles. — **E. B.**

WEBTALK

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BY KARRI FERRON

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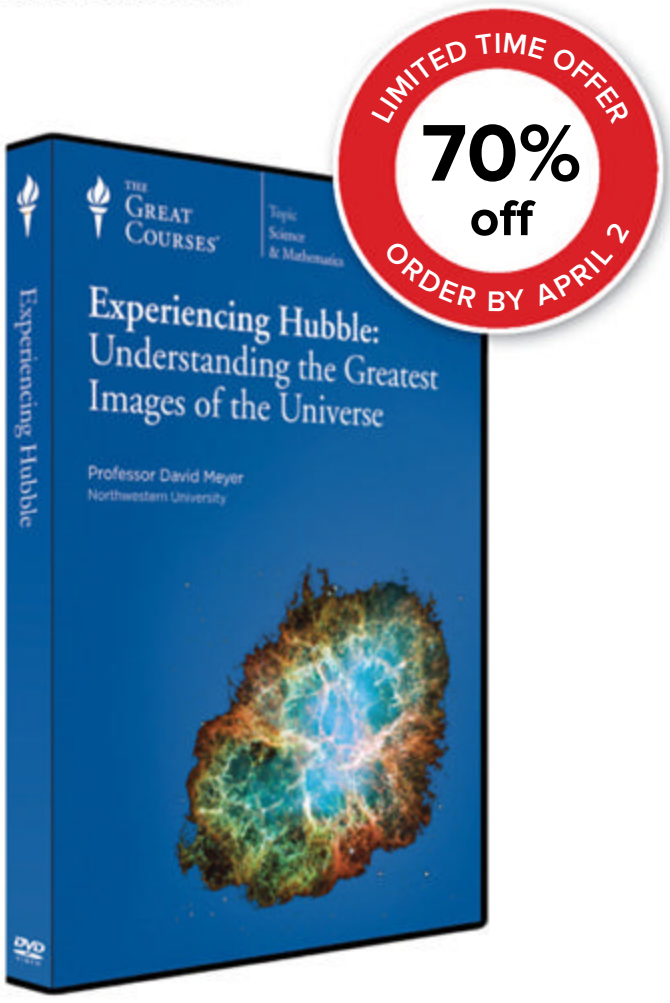

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The man behind the Pillars

What has **Jeff Hester***'s iconic Hubble Space Telescope image of the Eagle Nebula meant to him personally?*

The Eagle Nebula's "Pillars of Creation" were captured April 1, 1995, with the Hubble Space Telescope's Wide-Field and Planetary Camera 2. Jeff Hester and Paul Scowen assigned different colors to emission from different atoms in the false-color image: red shows sulfur, green hydrogen, and blue oxygen. NASA/ESA/STScI/J. HESTER AND P. SCOWEN (ARIZONA STATE UNIVERSITY)

Not everyone winds up seeing their work on a U.S. postage stamp or in *Time*'s collection of the 100 most influential photographs in history. It's cool to see the "Pillars of Creation" on the big screen in a sci-fi blockbuster or hanging on the window of Sheldon and Leonard's apartment on *The Big Bang Theory*. It's fun to hear the phone ring and have a friend say, "Hey, I just saw you on TV again!" It's been quite a ride, made especially rewarding because I was part of the team that built Hubble's Wide-Field and Planetary Camera 2.

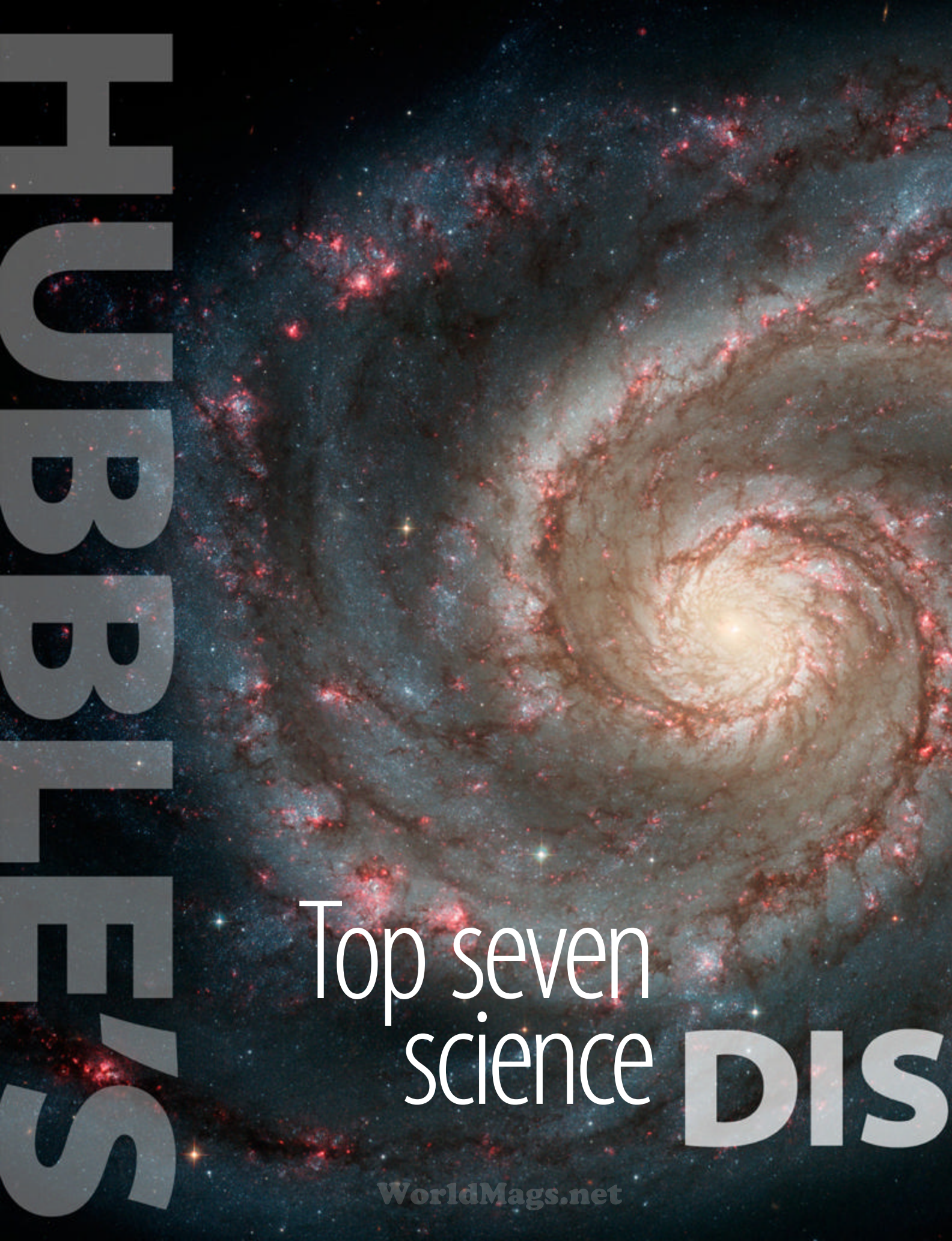
The Eagle Nebula image symbolized an end to what had been a very difficult period for NASA. That is what it was designed to do. The press conference was scheduled to coincide with a feature article in *Time* heralding Hubble's phoenix-like rise from early disaster. How better to illustrate that story than with a stunning image unlike anything the public had ever seen? But no one imagined a reaction that would turn the image into a cultural icon.

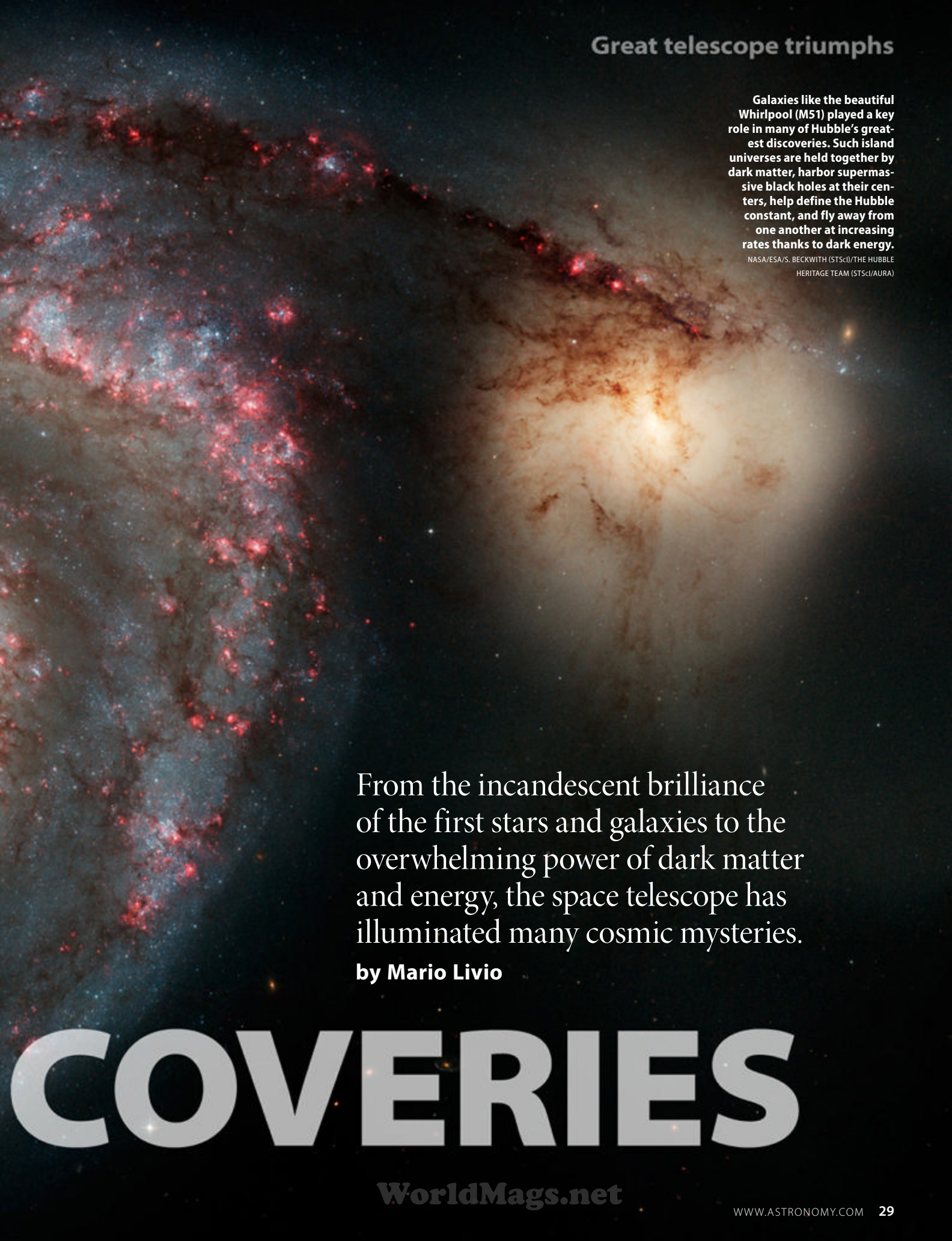
For as long as there have been humans, we have looked at the night sky in awe and wondered about our connection with the heavens. Now for the first time in history, we can tell that story, beginning with the Big Bang and ending with us sitting here talking about it. Knowledge of our place in the universe is no longer a matter of speculation or mythology. It is hard science. For many, the Pillars of Creation became the recognized face of that human triumph.

I have spent countless hours discussing the image not only with fellow scientists, but also with artists, musicians, writers, and in fact people from all backgrounds. They would speak of beauty and passion and inspiration. The more I listened, the more familiar their reactions sounded to my own. We were all expressing our experience of the human drive to find patterns and meaning in the midst of the complexity of the world.

Astronomy asked me, "What has the image meant to you personally?" There is no doubt that it reshaped my career as a scientist. But more than that, it changed not only the way I think about science and art, but also my understanding of what it is to be human.

Jeff Hester *is a professor emeritus of Arizona State University. These days, he is working as a professional coach and speaker, sharing his experiences and perspectives with individuals and organizations.*



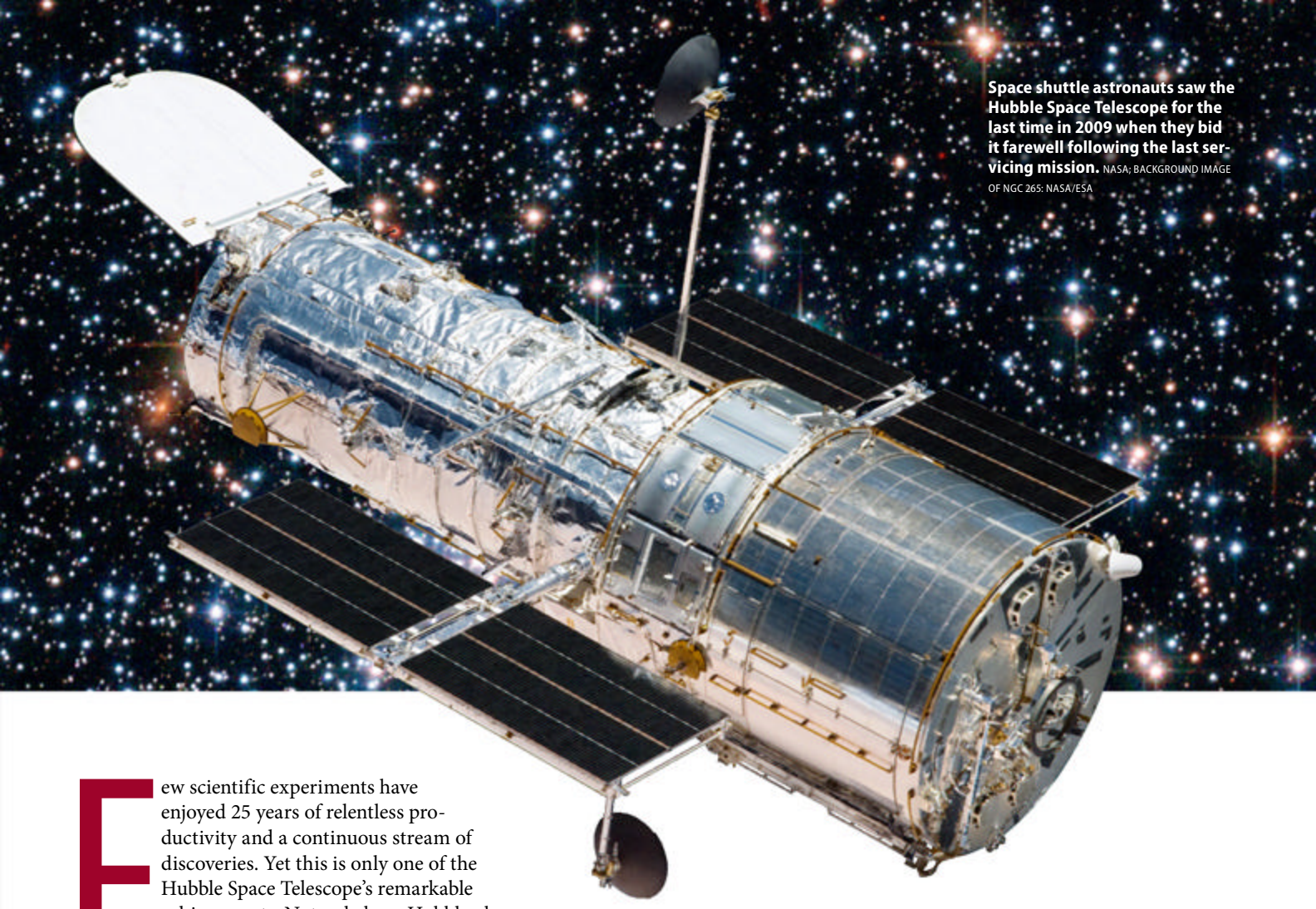


Galaxies like the beautiful Whirlpool (M51) played a key role in many of Hubble's greatest discoveries. Such island universes are held together by dark matter, harbor supermassive black holes at their centers, help define the Hubble constant, and fly away from one another at increasing rates thanks to dark energy.
NASA/ESA/S. BECKWITH (STScI)/THE HUBBLE HERITAGE TEAM (STScI/AURA)

From the incandescent brilliance of the first stars and galaxies to the overwhelming power of dark matter and energy, the space telescope has illuminated many cosmic mysteries.

by Mario Livio

COVERIES



Space shuttle astronauts saw the Hubble Space Telescope for the last time in 2009 when they bid it farewell following the last servicing mission. NASA; BACKGROUND IMAGE OF NGC 265: NASA/ESA

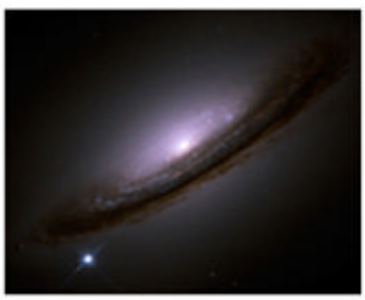
Few scientific experiments have enjoyed 25 years of relentless productivity and a continuous stream of discoveries. Yet this is only one of the Hubble Space Telescope's remarkable achievements. Not only have Hubble observations transformed our ideas about almost every topic in astronomy and astrophysics, but the drama associated with space shuttle astronauts servicing the observatory and the impact the telescope has had on the public's appreciation of science also have made Hubble unique in the history of science.

Hubble's scientific successes are so numerous that it is not easy to select its greatest hits. Consequently, the list on the following pages represents my own personal biases as to what the telescope's most important contributions have been.

I also should emphasize that it is rare in astronomy to be able to attribute a discovery to one particular observation or a specific observatory. More often, progress in understanding phenomena results from a series of observations at different wavelengths by a variety of telescopes over a long period of time. I do not claim, therefore, that Hubble acted alone in making these seven discoveries. Instead, I chose findings in which space telescope observations played a crucial role.

In selecting Hubble's most important breakthroughs, I was guided by two principles: Either the discovery had to contribute significantly to our understanding of the universe as a whole, or it had to represent a major step in the quest to determine whether extraterrestrial life exists. The second point arguably ranks as one of the most intriguing pursuits in science today.

Mario Livio *is a senior astrophysicist at the Space Telescope Science Institute in Baltimore, which conducts the scientific program of Hubble. His most recent book is* Brilliant Blunders *(Simon and Schuster, 2013).*



Supernova 1994D (lower left) in galaxy NGC 4526 helped astronomers pin down the universe's accelerating expansion, which is powered by a repulsive force exerted by dark energy. NASA/ESA/THE HUBBLE KEY PROJECT TEAM/THE HIGH-Z SUPERNOVA SEARCH TEAM

Dark energy

The gravitational attraction of all the matter in the universe should cause cosmic expansion to slow down. But in 1998, two groups of astronomers discovered the exact opposite: The rate of universal expansion is accelerating. The researchers based their discovery on observations of stellar explosions known as type Ia supernovae, which occur when white dwarf stars grow to their limiting mass of about 1.4 solar masses. Only Hubble could view the most distant of these explosions and thus confirm the acceleration.

All current studies indicate that a still-mysterious form of energy, dubbed dark energy, propels this speed-up. Although scientists do not yet understand the precise nature of dark energy, they have deduced some of its properties. These efforts suggest that it is the energy associated with empty space, or what scientists call the physical vacuum.

That the vacuum contains energy is not surprising in itself. Quantum mechanics — the physics that describes the universe at the smallest scales — predicts that the physical vacuum is far from empty. Instead, it teems with virtual pairs of particles and

NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)/R. GENDLER (FOR THE HUBBLE HERITAGE TEAM)

Water megamasers — amplified microwave emissions from water molecules — orbiting the central supermassive black hole in spiral galaxy M106 pinned down this object's distance. Hubble's calibration of Cepheid variable stars in the galaxy played a crucial role in determining the Hubble constant.

antiparticles that appear and disappear within tiny fractions of a second. The problem has been that every theoretical attempt to calculate what the energy density of the vacuum should be has missed the target by several orders of magnitude.

Given the quickening expansion, what will the fate of our universe look like in the distant future? If dark energy does represent the energy of empty space, which has a constant density, then the expansion will continue to accelerate. About a trillion years from now, astronomers living in the merged product of the Milky Way and the Andromeda Galaxy — the two are expected to collide about 4 billion years from now (another Hubble result, by the way) — will not be able to see any other galaxy. The universe then will be well on its way toward a cold death.

The Hubble constant and the universe's age

Ever since the 1920s and the seminal works of astronomers Vesto Slipher, Georges Lemaître, and Edwin Hubble, scientists have known that the universe is expanding. The so-called Hubble constant is a measure of the current expansion rate, and its value is inversely proportional to the age of the universe. Until the space telescope's launch, published values of the Hubble constant differed by as much as a factor of two. One large group of astronomers claimed a value around 50 kilometers per second per megaparsec, while the other main faction declared a rate near 100 km/s/Mpc. And each side in the argument insisted that their data supported an improbable error of only about 10 percent.

One of Hubble's "key projects" was to resolve this conundrum. Using the space telescope's superb optical resolution, the key project team examined a number of distance indicators, including Cepheid variable stars, the Tully-Fisher relation that links a spiral galaxy's rotation rate to its intrinsic luminosity, and type Ia supernovae. By 2001, the team refined the Hubble constant's value to 72 km/s/Mpc with a precision of about 10 percent.

Few scientific experiments have enjoyed 25 years of relentless productivity and a continuous stream of discoveries.

A combination of this new value with the discovery of cosmic acceleration and a new assessment of the ages of globular star clusters resolved yet another mystery — the universe is indeed older than its oldest known stars. For cosmologists who believed in a Hubble constant of 100 km/s/Mpc, a simple calculation shows that the universe would be only about 10 billion years old, yet the ancient stars in globular clusters appeared to be at least 12 billion years old. According to the most recent determination of cosmological parameters by the European Space Agency's Planck satellite, the universe is 13.8 billion years old with an uncertainty of just 40 million years.

But scientists have not rested on their laurels. Thanks largely to further Hubble observations, in the past decade astronomers have made impressive progress in measuring the Hubble constant more precisely. By cross-calibrating several distance indicators — such

The Hubble Deep Field South seen here is one of a series of observations astronomers made with Hubble that helped establish the cosmic star-formation rate. R. WILLIAMS (STScI)/THE HDF-S TEAM/NASA/ESA

as Cepheid variables, type Ia supernovae, and the amplified microwave emissions from water molecules (so-called megamasers) in orbit around the supermassive black hole at the center of galaxy M106 — they reduced the uncertainty in the Hubble constant's value to about 5 percent by 2009 and to 3 percent by 2011.

Currently, researchers are using new scanning techniques with Hubble's Wide Field Camera 3 to get even more precise distances to Cepheids in the Milky Way at distances of about 3,000 to 10,000 light-years. These promise to shrink the Hubble constant's uncertainty to just 2 percent. And the European Space Agency's ongoing Gaia mission should make robust progress by extending accurate Cepheid observations out to 33,000 light-years.

Refining the Hubble constant in the relatively nearby universe to a precision of 1 percent may help resolve the latest apparent tension between different measurements. The so-called local value currently stands at about 73 km/s/Mpc, while that inferred from Planck observations of the distant universe holds at about 68 km/s/Mpc. The discrepancy may reflect only higher systematic errors than anyone suspects, but if it turns out to be real, it hints at some potentially new physics.

The cosmic star-formation rate

Some of Hubble's most dramatic observations have been long-exposure photographs of what, at first blush anyway, appeared to be rather bland areas. Starting with the original Hubble Deep Field — an observation made of a tiny region in the constellation Ursa Major over 10 days in December 1995 — the space telescope has carried out several deep observations of small patches of sky. These programs have revealed just how small our physical existence is in the grand cosmic scheme.

Each deep field exposed thousands of galaxies in an area of sky you would see looking through a drinking straw. Given that the cosmos appears to be homogenous and isotropic — the same at every location and in every direction — these findings imply that the observable universe holds a few hundred billion galaxies.

Each deep field exposed thousands of galaxies in an area of sky you would see looking through a drinking straw.

The deep observations have provided astronomers with a treasure-trove of data about galaxy evolution. One key result has been learning the cosmic star-formation rate — how fast the universe as a whole creates new stars as a function of distance, or cosmic time. (See "How fast do stars form?" below.) Knowing how quickly stellar mass builds up in galaxies provides fundamental constraints on models of how galaxies form and evolve.

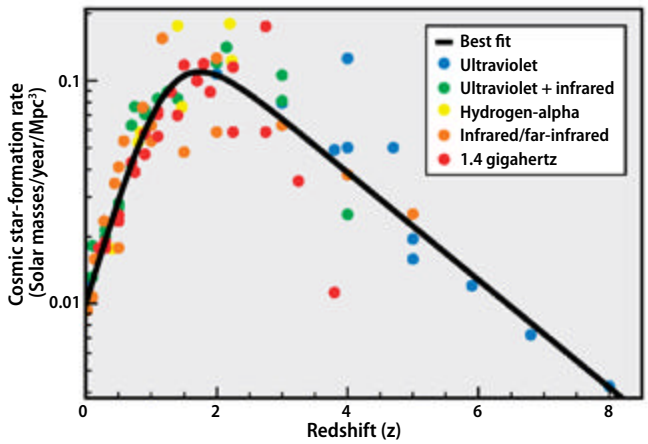
Black holes at the centers of galaxies

Even before Hubble opened its eyes to the universe, observations indicated that at least some galaxies harbor supermassive black holes in their cores. And theoretical models of active galaxies and of quasars — extraordinarily energetic point-like objects in the distant universe — suggested that matter accreting onto such black holes from their surroundings powered their emissions. Hubble observations turned these hints and tentative ideas into certainty.

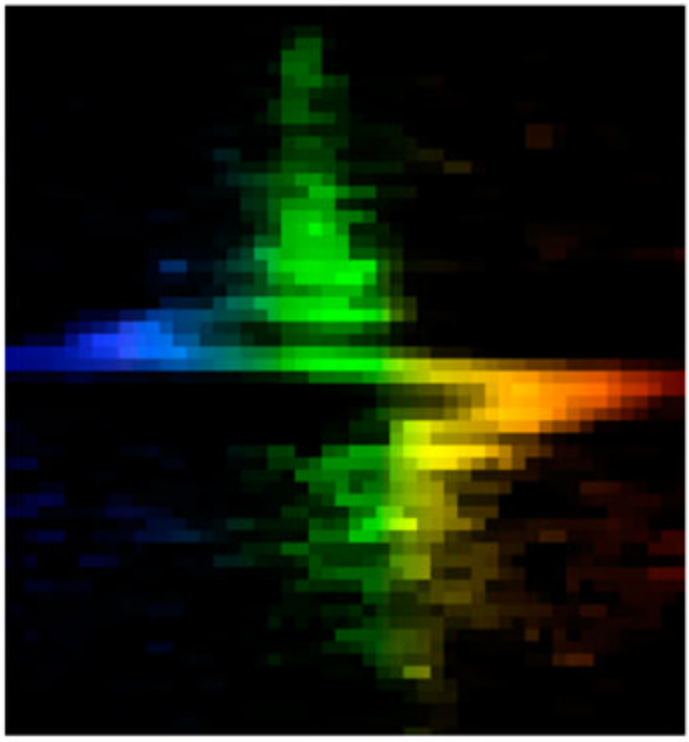
The space telescope has shown that essentially every galaxy that has a bulge of stars at its center hosts a supermassive black hole. These black holes range in mass from perhaps as low as a few tens of thousands of times the Sun's mass in dwarf galaxies to a few billion solar masses in massive galaxies. Hubble also has directly imaged the host galaxies of a few quasars, demonstrating unambiguously that the engines driving these objects reside at the centers of galaxies.

Most significantly, however, Hubble observations revealed a fairly tight correlation between the relative speeds of the stars in the galaxy's central bulge (what astronomers call the velocity dispersion) and the mass of the black hole. The velocity dispersion, in turn, depends on the mass of the bulge.

How fast do stars form?

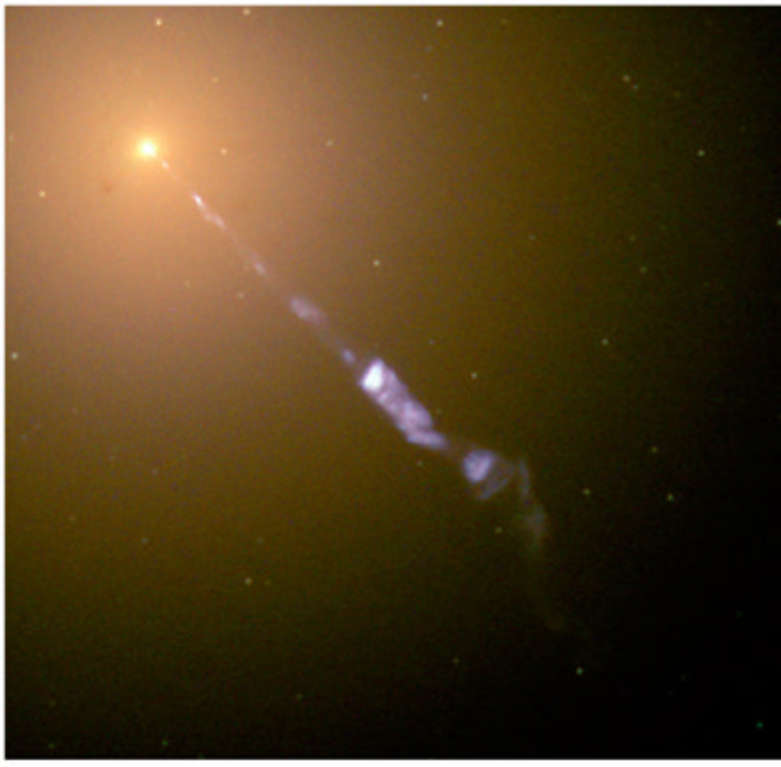


The cosmic star-formation rate peaked at a redshift of around 2 (which corresponds to a look-back time of 10 billion years). Today's universe produces only 0.01 solar mass of stars per year in a typical cubic megaparsec (Mpc), which is approximately 35 million cubic light-years. *ASTRONOMY*: ROEN KELLY, AFTER P. S. BEHROOZI, R. H. WECHSLER, AND C. CONROY (*ApJ*, 770, 57)



GARY BOWER AND RICHARD GREEN (NOAO)/THE STIS INSTRUMENT DEFINITION TEAM/NASA

A spectrum of the central regions of M84, a giant elliptical galaxy in the Virgo Cluster, shows a sharp shift in the velocity of gas clouds from high-speed approach (blue) to rapid recession (red), indicating the presence of a supermassive black hole at the center.



A jet of high-speed particles shoots from the center of an accretion disk that surrounds the black hole at the center of the galaxy M87. The black hole tips the scales at about 3.5 billion solar masses. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

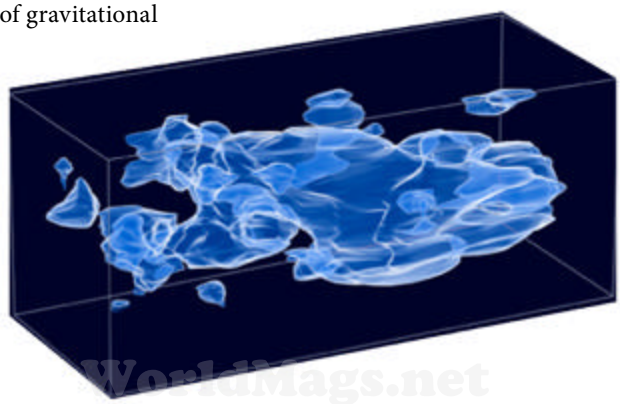
This relation has important implications for galaxy evolution. It demonstrates that a galaxy and its central black hole do not evolve independently. Rather, the masses of the stellar bulge and the black hole grow in tandem. The picture that emerges suggests that as long as gas flows into a galaxy's center and the black hole accretes some of this material, the bulge continues to form new stars. Once radiation from the central engine and kinetic energy from supernova explosions blow the gas out, the growths of both the black hole and the bulge terminate.

Dark matter

As its name implies, dark matter neither emits nor absorbs electromagnetic radiation. Astronomers can infer its presence only through its gravitational effects. On the scale of a single galaxy, stars and gas clouds move too quickly for the pull of visible matter alone to hold them in bound orbits. The same is true for galaxies moving within galaxy clusters, which would disperse quickly without the dark matter glue. Dark matter constitutes about 85 percent of the universe's mass and provides the scaffolding on which nature erects its visible large-scale structure.

Hubble scientists used the phenomenon of gravitational lensing, in which the gravity of dark matter surrounding a galaxy cluster distorts the light from more distant objects, to create the largest three-dimensional map of dark matter's distribution. In addition, studies by Hubble of specific galaxy clusters, such as Abell 1689, have helped researchers create detailed dark-matter maps for these objects. These maps have helped constrain models for how galaxy clusters grow.

Hubble observations of the Bullet Cluster show its distribution of dark matter (inferred from gravitational lensing) in blue; Chandra X-ray data (in red) reveals the site of ordinary hot gas. X-RAY: NASA/CXC/M. MARKEVITCH, ET AL.; OPTICAL: NASA/STScI; MAGELLAN/U. ARIZONA/D. CLOWE, ET AL.; LENSING MAP: NASA/STScI; ESO WFI; MAGELLAN/U. ARIZONA/D. CLOWE, ET AL.



Cosmologists long suspected that dark matter creates a universal weblike structure that acts as scaffolding for normal matter. In 2007, researchers combined Hubble observations with those from large ground-based instruments to come up with this first large-scale 3-D map of dark matter. NASA/ESA/R. MASSEY (CALTECH)

The Hubble eXtreme Deep Field (XDF) shows galaxies out to the most distant reaches of the cosmos, close to the time when the first stars were starting to reionize the universe. NASA/ESA/G. ILLINGWORTH, D. MAGEE, AND P. OESCH (UNIVERSITY OF CALIFORNIA, SANTA CRUZ)/R. BOUWENS (LEIDEN UNIVERSITY)/THE HUDF09 TEAM

Perhaps most importantly, Hubble observations in combination with those of the Chandra X-ray Observatory and ground-based telescopes have shown a clear separation between the dark matter and the hot ordinary gas present in colliding galaxy clusters. Astronomers were not surprised to see such a division. After all, the ordinary gas in the two clusters collides and forms shock waves while the dark matter passes through without any electromagnetic interaction.

Hubble now has observed this phenomenon in the Bullet Cluster (1E 0657–56), Pandora's Cluster (Abell 2744), and MACS J0025.4–1222. Scientists consider it to be the best evidence yet for the weakly interacting nature of dark matter.

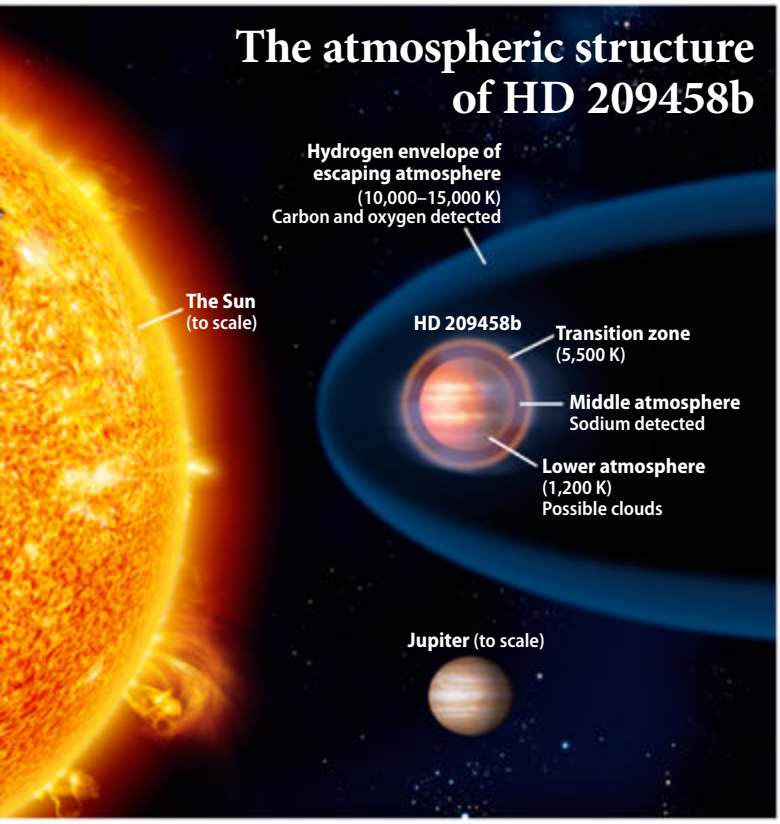
Reionization in the early universe

A few minutes after the Big Bang, the universe was filled with a hot plasma composed mainly of protons and free electrons. As the cosmos expanded and cooled, it reached a point some 380,000 years later at which it went through a phase transition — protons and electrons combined to form neutral hydrogen atoms. With the electrons trapped inside atoms, the universe became transparent to light. In the 13.8 billion years since, the expanding cosmos has shifted this radiation to much longer wavelengths in the microwave part of the electromagnetic spectrum.

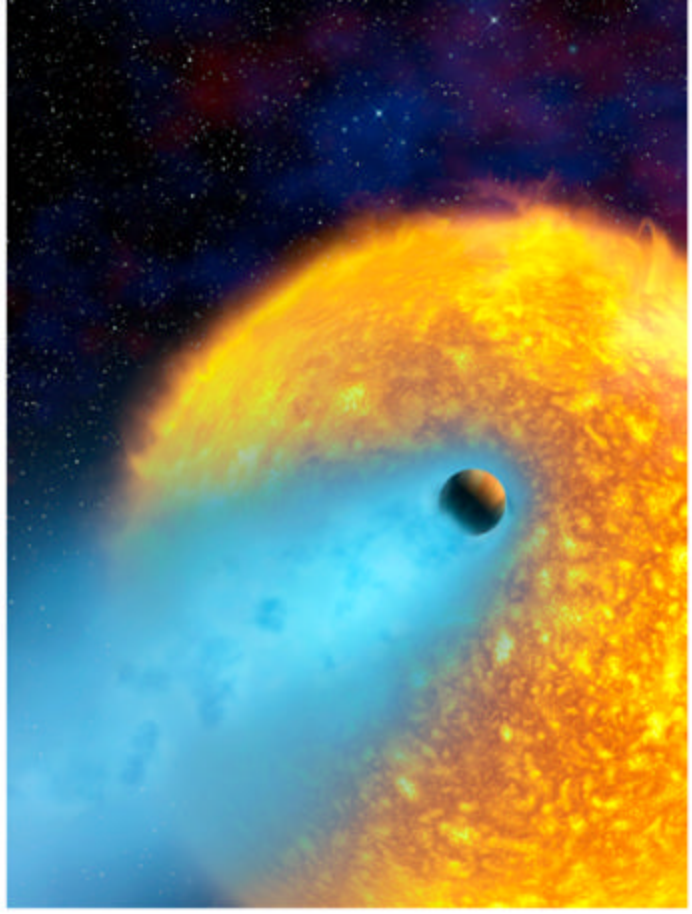
This phase transition marks not only the birth of the cosmic microwave background but also the beginning of the so-called Dark Ages, the period when no sources of light such as stars or galaxies yet existed. When the universe reached an age of about 100 to 200 million years, it started forming stars. Astronomers think that these earliest stars produced ultraviolet radiation that, perhaps with the help of X-rays emitted by X-ray binary systems, reionized the cosmos. By the time the universe was about a billion years old, this reionization was complete.

One of the key questions in modern cosmology asks what the main energy sources responsible for reionization were. By reaching back to times when the universe was about 500 million years old, the various Hubble deep fields have explored the galaxy population well into the reionization era.

Aided by some reasonable assumptions about the fraction of photons capable of ionizing hydrogen atoms that escaped from these young galaxies and the clumpiness of the intergalactic medium at these early times, these studies show that if star-forming galaxies fully reionized the universe, the population of these objects must extend to luminosities fainter than Hubble can reach. This is an interesting constraint because the upcoming James Webb Space Telescope (JWST) will be able to explore such faint objects — if they indeed exist.



Hubble observations allowed astronomers to deduce the atmospheric structure of exoplanet HD 209458b, which features a lower and middle atmosphere surrounded by an extended hydrogen envelope that bleeds into space. *ASTRONOMY*: ROEN KELLY, AFTER NASA/ESA/A. FEILD (STScI)



This artist's illustration shows the atmosphere of the planet HD 209458b, a "hot Jupiter" in a 3.5-day orbit around a star with about 15 percent more mass than the Sun, as it evaporates under the intense radiation. ESA/ALFRED VIDAL-MADJAR (INSTITUT D'ASTROPHYSIQUE DE PARIS, CNRS, FRANCE)/NASA

The atmospheres of exoplanets

Since 1991, a series of observations made from the ground and by the Kepler spacecraft has revealed nearly 2,000 planets orbiting stars other than the Sun. Although some astronomers continue to hunt for new exoplanets, others have started to focus on exploring the atmospheric compositions of known exoworlds. Ultimately, researchers hope these investigations will lead to the detection of significant biosignatures — signs of life produced by plants, photosynthetic bacteria, or other biological processes. Biosignatures include molecules such as oxygen, ozone, and chlorophyll, as well as atmospheric conditions on Earth-like exoworlds that are not in equilibrium.

Observations of transiting planets — those whose orbital planes lie edge-on to our line of sight — made with Hubble and the infrared-sensitive Spitzer Space Telescope already have detected several atoms and molecules in the atmospheres of a few "hot Jupiters" and "hot Neptunes." These giant planets orbit close to their host stars and, as a result, have toasty extended atmospheres.

During a so-called primary eclipse, when a transiting planet slides in front of its star, a small fraction of the star's light must pass through the planet's atmosphere. Analyzing the stellar spectrum can reveal the presence of certain elements in that gaseous envelope. This is how Hubble discovered sodium in the atmosphere of a world cataloged as HD 209458b. In another set of observations, the space telescope detected hydrogen, carbon, oxygen, and water vapor in this planet's atmosphere. Hubble also found water vapor in the atmosphere of HD 189733b.

Spitzer researchers have detected water vapor in planetary atmospheres during secondary eclipses, when the planet hides behind the star. In this technique, scientists subtract the light of the star alone (when the planet is behind it) from the combined light of star and planet (when the planet is in view) to see emission from the orbiting world's atmosphere.

Both Hubble and Spitzer have discovered clouds in the atmospheres of several exoplanets, including Kepler-7b, GJ 436b, and GJ 1214b. Astronomers expect to be able to characterize the atmospheres of even smaller exoplanets with the upcoming JWST, scheduled for launch in 2018.

Observations of transiting planets . . . have detected several atoms and molecules in . . . a few "hot Jupiters" and "hot Neptunes."

Twenty-five wonderful years

Through these discoveries and more, Hubble has informed or altogether changed our views on the universe and on the potential existence of life within it. On one hand, Hubble has shown us how small we are compared to the vastness of the cosmos and how brief our lives are compared to cosmic time. On the other hand, the space telescope has proved that we actually can attempt to understand all the phenomena we observe out to the universe's most distant corners. As Albert Einstein once said: "The eternal mystery of the world is its comprehensibility … the fact that it's comprehensible is a miracle." There is no doubt that the Hubble Space Telescope has helped to make it comprehensible.

DISCOVER MORE ON WHAT SCIENTISTS HAVE LEARNED FROM THE HUBBLE DEEP FIELDS AT **www.Astronomy.com/toc.**

MARTIN RATCLIFFE and **ALISTER LING** describe the solar system's changing landscape as it appears in Earth's sky.

Visible to the naked eye
Visible with binoculars
Visible with a telescope

April 2015: A brief glimpse of totality

Viewers in western North America can expect a bright total lunar eclipse April 4 because the Full Moon will be traveling through the northern edge of Earth's umbral shadow. This image captures the nearly reversed lighting seen during totality April 15, 2014. JOEL TONYAN

April showers may bring May flowers, but this month's finest shower could deliver a tempest of meteors. Lyrid meteors will rain down the night of April 22/23, providing viewers with their first Moon-free major shower of 2015. The Moon will be in plain sight for the month's top celestial event, however, when our fully lit satellite passes through Earth's shadow for a spectacular total eclipse in the wee hours of April 4.

These short-lived events depend on nice weather occurring on specific dates. But you can spy the best of April's planets on any clear night. Venus and Jupiter dominate the evening scene, while Saturn appears at its best in the early morning hours.

When it comes to record-setting events, the April 4 **total lunar eclipse** certainly ranks high. The Full Moon passes through Earth's dark umbral shadow for 4 minutes and 43 seconds, which makes this the 21st century's briefest view of totality. In fact, you need to go back to October 17, 1529, to find a shorter total lunar eclipse (only 1 minute and 41 seconds long).

From North America, better views of the eclipse come the farther west you live. From east of the Mississippi River, people will see only the eclipse's initial partial phases during morning twilight. Everyone else will see totality, but the Moon will appear much higher and in a dark sky from the West Coast. The eclipse's partial phases begin at 6:16 A.M. EDT (3:16 A.M. PDT), and totality starts at 4:58 A.M. PDT.

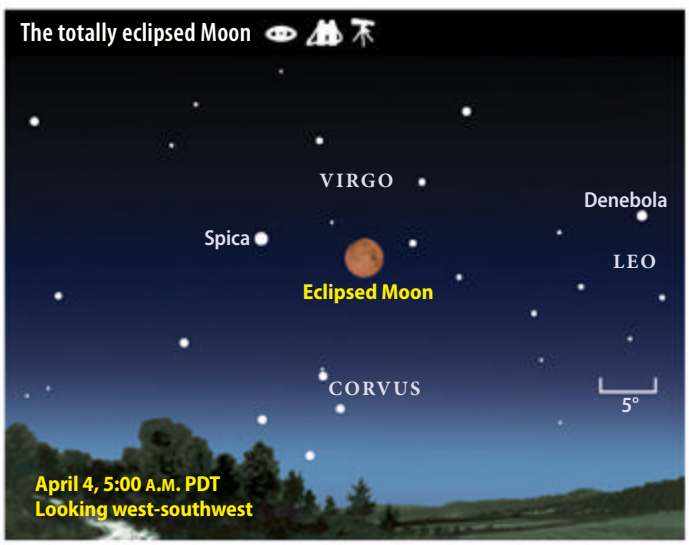
Let's begin our tour of April planets in the western sky during evening twilight. **Mars** sets about 90 minutes after the Sun on the 1st and stands 5° above the horizon a half-hour later. It shines rather dimly at magnitude 1.4 and should show up to naked eyes, though binoculars certainly will help the cause. The Red Planet becomes increasingly hard to see as the month progresses and it dips lower in twilight.

Although **Mercury** passes behind the Sun on April 9, it reappears in the evening sky within 10 days. This starts the innermost planet's best evening appearance of the year for Northern Hemisphere observers. It will reach its peak separation from the Sun in early May, but appears brighter in late April.

You can look for Mercury beginning April 19. Use binoculars to search for the magnitude –1.4 planet 7° to the lower right of a barely day-old Moon. Three days later, on the 22nd, Mercury stands 1.3° north of Mars. The inner world should be easy to spot at magnitude –1.1, but the Red Planet is 10 times fainter and will be a challenge even with binoculars.

Mercury's motion against the background stars continues through month's end, and by the 30th, it reaches a point 1.7° south of the Pleiades star cluster (M45). The magnitude –0.4 planet then lies 7° high in the west-northwest an hour after sunset.

As Mercury swings toward Earth in late April, a telescope shows its increasing size and dwindling phase. On the 19th, the planet appears 6" across and about 90 percent



The eclipsed Moon of April 4 stands among the background stars of Virgo, just 10° from 1st-magnitude Spica. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*

RISING**MOON**

A marvelous night for a Moon dance

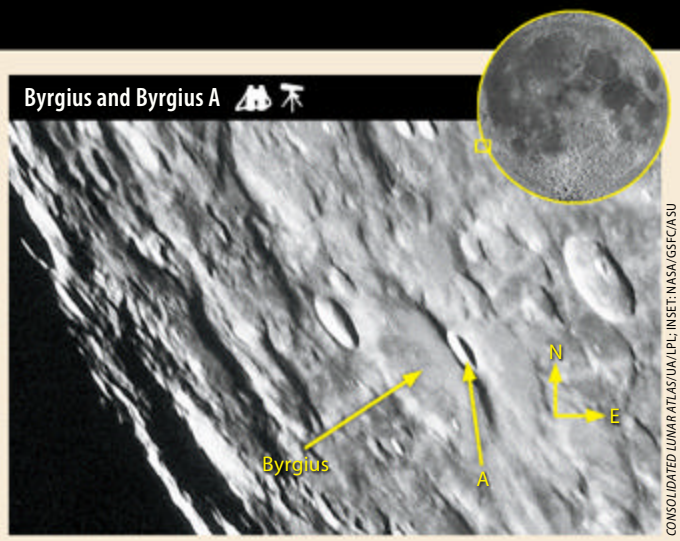
The endearing couple of Terra and Luna glides quietly across the solar system's dance floor every month. From our earthly perspective, the Moon appears to circle us, at times leading and then following, but it actually never moves backward relative to the audience of stars. What it does do is change speeds as its distance from Earth changes, initiating a dance astronomers call "libration." If you concentrate on our neighbor's face during April, you can see this libration as the phases wax and wane.

Start with the crater Byrgius, which resides in the Moon's southwestern corner. Although this 54-mile-wide impact feature doesn't stand out, a much smaller crater on its eastern rim does. The youngster Byrgius A boasts a bright ray system that appears quite prominent even through binoculars. Each night after the April 4 Full Moon, this dazzling dimple rotates into better view because the Moon is moving more slowly than normal, letting us peek a bit past its normal southwestern limb.

We swap places during the passage through New Moon and arrive at First Quarter on April 25 getting great views of the opposite limb. Using binoculars on the 25th or 26th, look for a trio of dark spots on the northeastern limb: Lacus Spei, Endymion, and Mare Humboldtianum.

With each step toward the next Full phase, Luna moves more slowly than usual and the trio rotates away from us. Mare Humboldtianum will disappear May 1, while the other two reach the limb at Full Moon on May 3. But by that time, Byrgius A has spun back into view.

Although we've come back to the same spot relative to the Sun's spotlight, Luna's more involved dance does not repeat exactly. That grander cycle takes some 18 years to complete.



Inconspicuous when the Sun lies low in the lunar sky, as seen here, Byrgius A displays bright rays near Full Moon.

lit. By the 30th, its disk spans 7" but sunlight illuminates less than 60 percent of it.

You won't have any problem finding **Venus** even during bright twilight. The planet shines at magnitude –4.1 for most of April, a dazzling diamond hanging in the western sky for three hours after sunset. Venus begins the month in the constellation Aries but soon crosses into Taurus, where it remains the rest of the month. It passes 3° south of the Pleiades on April 10 and 7° north of 1st-magnitude Aldebaran, Taurus' brightest star, on the 20th. The Bull's luminary appears to be the brightest member of the V-shaped Hyades star cluster, though the star actually lies only half as far away.

You'll want to be sure to catch the whole vista on the evening of the 20th. Not only is Venus 7° north of Aldebaran, but the waxing

— *Continued on page 42*

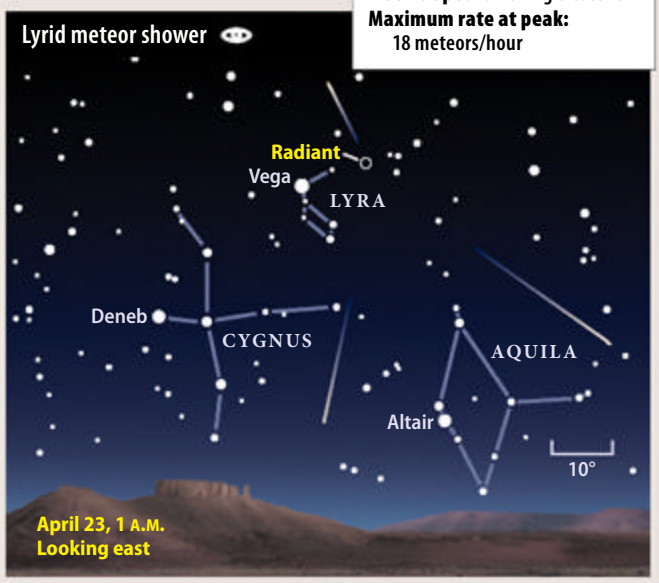
METEORWATCH

No Moon means good news for the Lyrids

Lyrid meteors
Active Dates: April 16–25
Peak: April 22/23
Moon at peak: Waxing crescent
Maximum rate at peak: 18 meteors/hour

We're already four months into the new year, and the skies still haven't delivered a good meteor show. A Full Moon blasted January's Quadrantids, and we've had only minor showers since. But that changes the night of April 22/23 when the annual Lyrid meteor shower reaches its peak. The waxing crescent Moon sets around midnight local daylight time, which leaves the prime viewing hours before dawn Moon-free.

Although the Lyrids typically deliver between 15 and 20 meteors per hour at their peak for observers at excellent sites, this year could be better. Some meteor scientists predict enhanced rates in 2015, so it could pay dividends to be watching before dawn April 23.



The April 23 morning sky features many shooting stars as the best meteor shower of 2015's first half reaches its peak.

OBSERVING HIGHLIGHT On April 4, viewers from central North America westward to Australia and eastern Asia will see a 5-minute total lunar eclipse.

STAR DOME

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight April 1
11 P.M. April 15
10 P.M. April 30

Planets are shown at midmonth

STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

See tonight's sky in Astronomy.com's STARDOME

APRIL 2015

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Calendar of events

1 The Moon is at apogee (252,284 miles from Earth), 9:01 A.M. EDT

4 Full Moon occurs at 8:06 A.M. EDT; total lunar eclipse

6 Uranus is in conjunction with the Sun, 10 A.M. EDT

8 The Moon passes 2° north of Saturn, 9 A.M. EDT

Jupiter is stationary, 4 P.M. EDT

9 Mercury is in superior conjunction, midnight EDT

SPECIAL OBSERVING DATE

10 Venus passes 3° south of the Pleiades star cluster in the evening sky.

11 Last Quarter Moon occurs at 11:44 P.M. EDT

15 The Moon passes 4° north of Neptune, 9 A.M. EDT

16 The Moon is at perigee (224,329 miles from Earth), 11:48 P.M. EDT

17 Pluto is stationary, 3 A.M. EDT

18 New Moon occurs at 2:57 P.M. EDT

19 Asteroid Pallas is stationary, 7 P.M. EDT

20 Asteroid Massalia is at opposition, 6 A.M. EDT

Venus passes 7° north of Aldebaran, midnight EDT

21 The Moon passes 0.9° north of Aldebaran, 1 P.M. EDT

The Moon passes 7° south of Venus, 2 P.M. EDT

22 Lyrid meteor shower peaks

25 First Quarter Moon occurs at 7:55 P.M. EDT

26 The Moon passes 0.1° south of asteroid Juno, 3 A.M. EDT

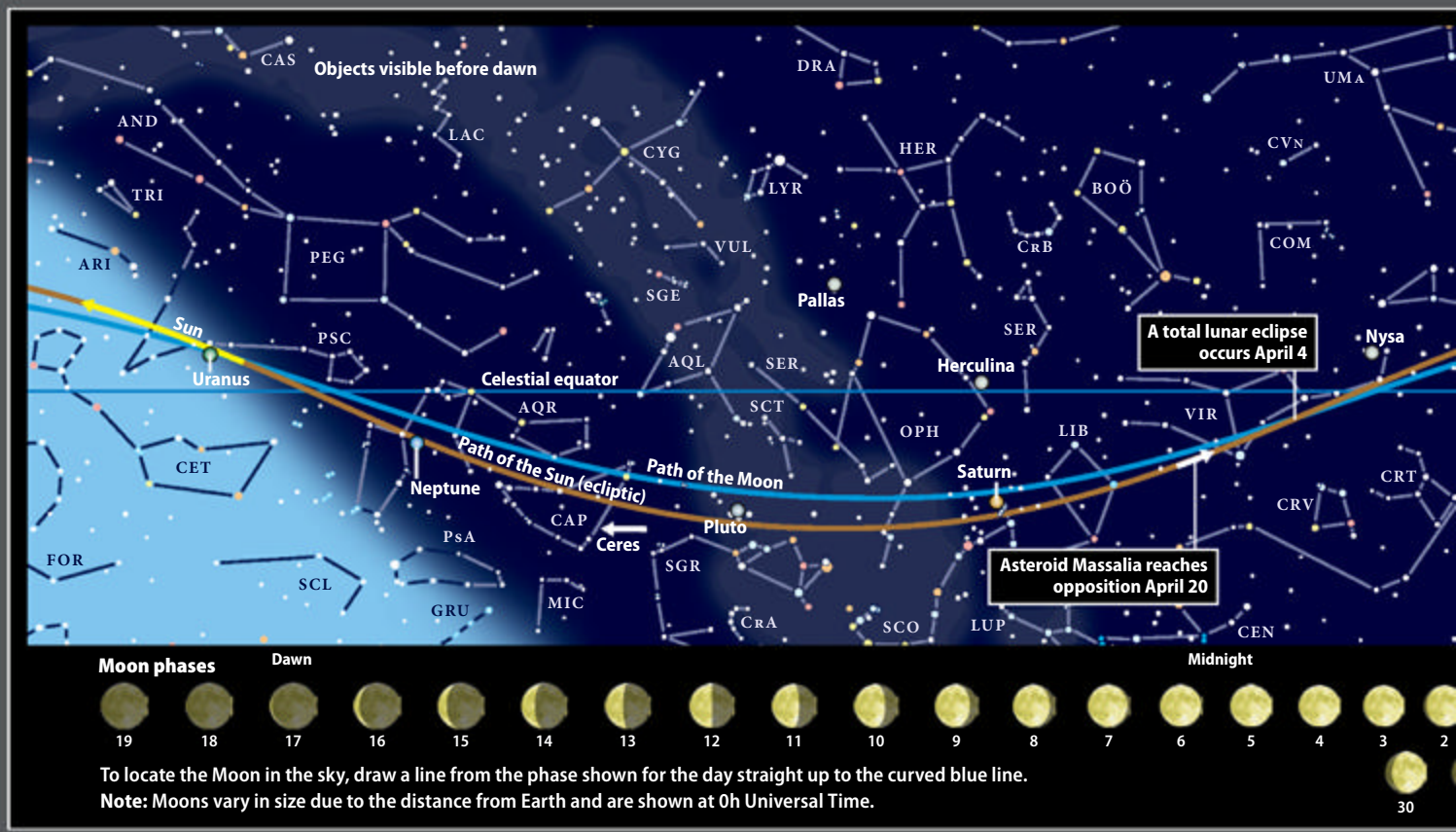
The Moon passes 5° south of Jupiter, 2 P.M. EDT

28 The Moon is at apogee (251,707 miles from Earth), 11:55 P.M. EDT

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

PATH OF THE PLANETS

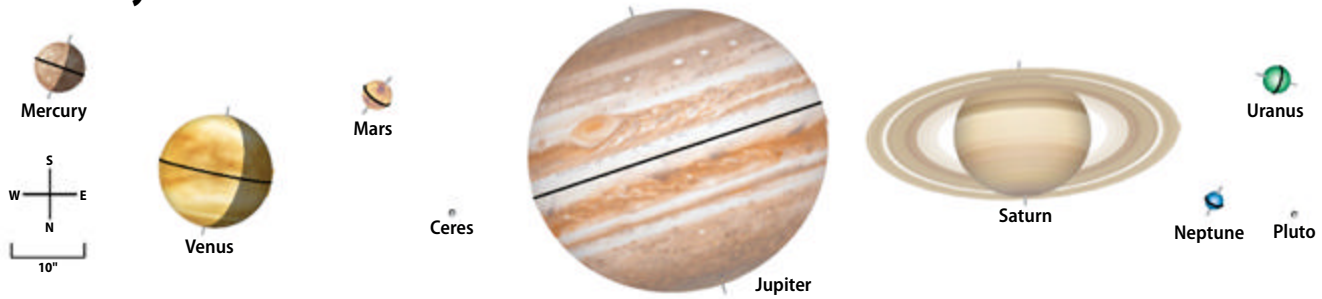
The planets in April 2015



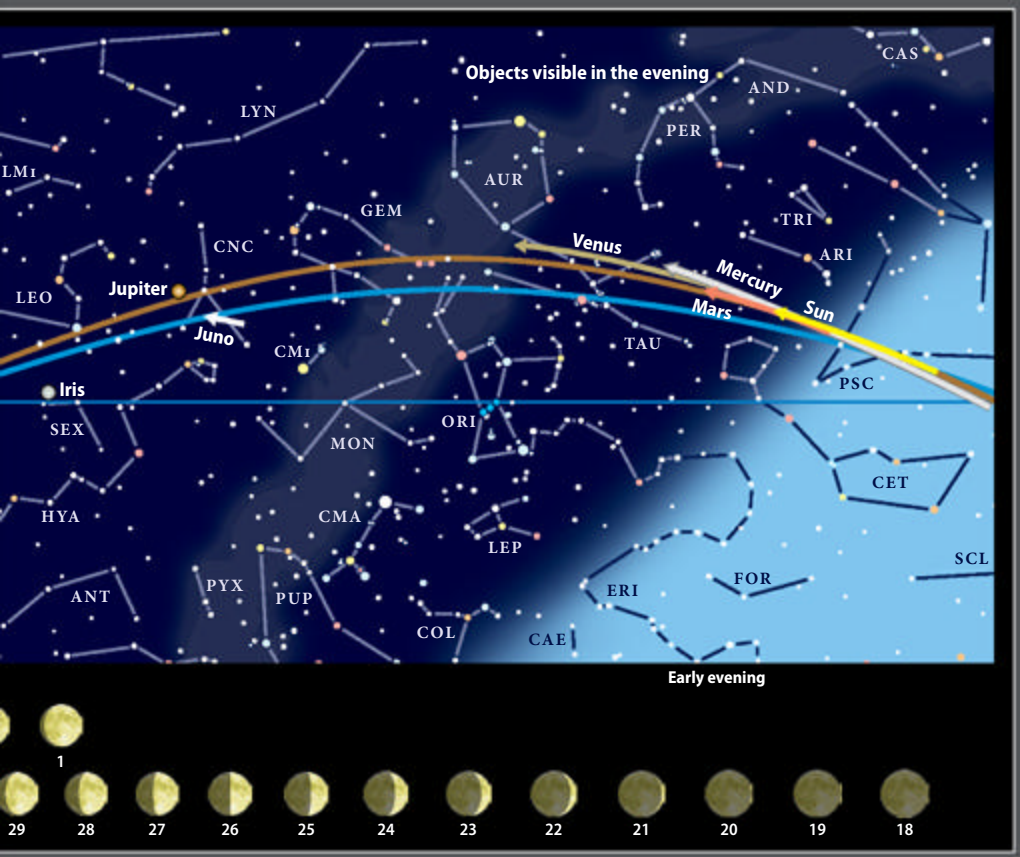
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.
Note: Moons vary in size due to the distance from Earth and are shown at 0h Universal Time.

The planets in the sky

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets for the dates in the data table at bottom. South is at the top to match the view through a telescope.

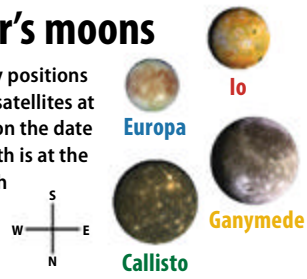


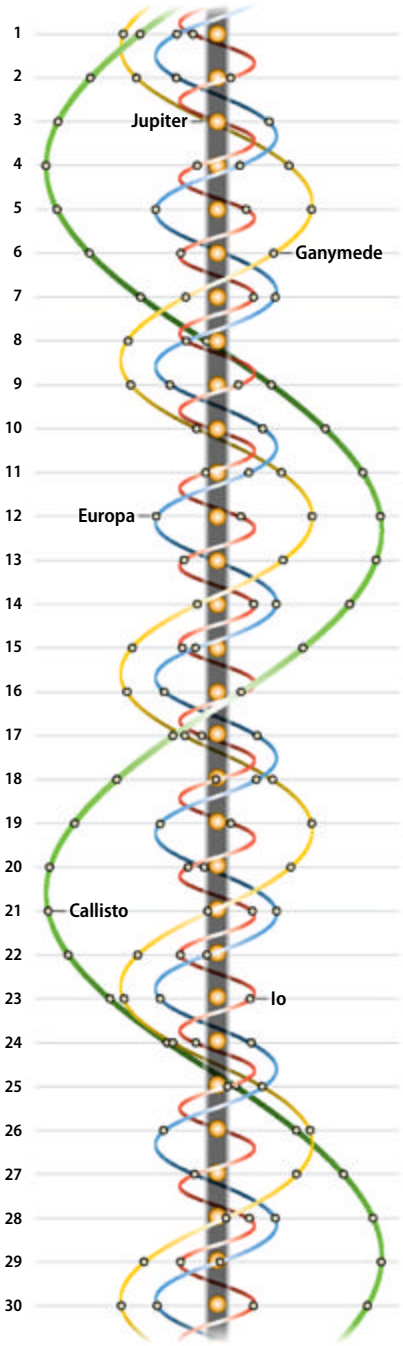
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	April 30	April 15	April 1	April 15	April 15	April 15	April 15	April 15	April 15
Magnitude	–0.5	–4.1	1.4	9.0	–2.2	0.2	5.9	7.9	14.2
Angular size	6.7"	15.0"	4.0"	0.5"	39.8"	18.1"	3.4"	2.2"	0.1"
Illumination	59%	73%	99%	97%	99%	100%	100%	100%	100%
Distance (AU) from Earth	1.011	1.114	2.362	2.860	4.958	9.177	20.991	30.657	32.678
Distance (AU) from Sun	0.337	0.718	1.457	2.893	5.352	9.972	19.998	29.966	32.853
Right ascension (2000.0)	3h41.6m	4h05.4m	1h51.9m	20h24.0m	9h00.7m	16h09.4m	1h02.6m	22h42.5m	19h05.5m
Declination (2000.0)	22°02'	22°31'	11°22'	–23°33'	17°59'	–18°48'	6°00'	–9°00'	–20°30'



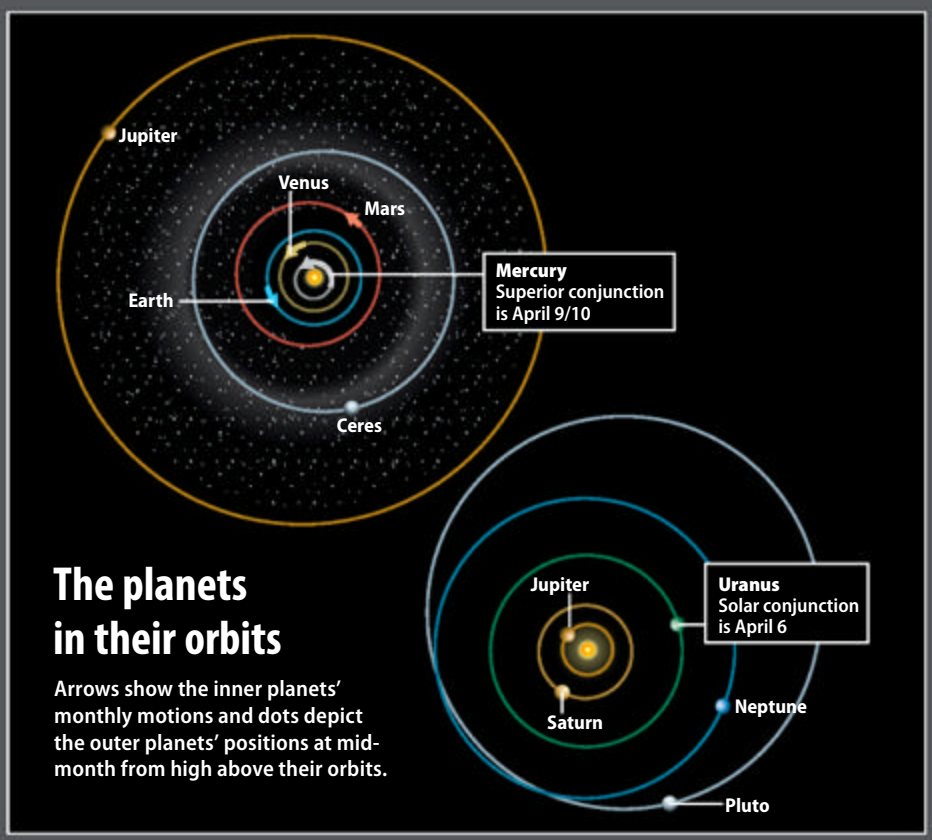
Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.





ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY



The planets in their orbits

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.

— Continued from page 37

WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Mercury (west)	Jupiter (west)	Saturn (southwest)
Venus (west)	Saturn (southeast)	Uranus (east)
Mars (west)		Neptune (east)
Jupiter (south)		

crescent Moon stands 7° west of the Hyades' center. The arrangement of the Moon, Venus, Hyades, and Pleiades creates a beautiful scene as the sky darkens. The next evening isn't too shabby either, with a noticeably fatter Moon standing 7° to the planet's left.

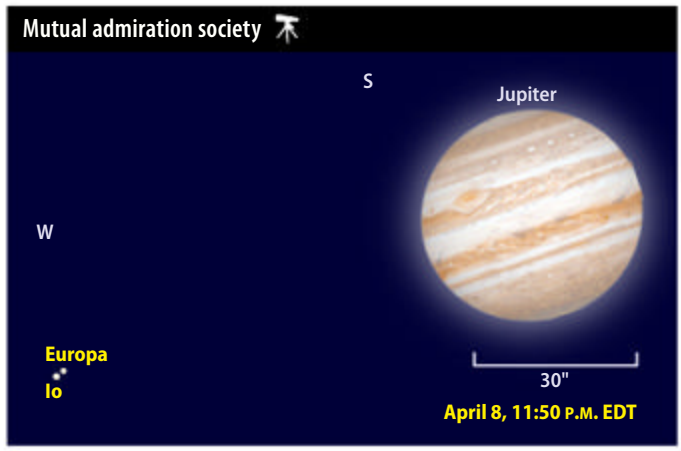
Like Mercury, Venus' telescopic appearance changes during April. The apparent diameter of its disk grows from 14" to 17" while the phase shrinks from 78 percent to 68 percent lit.

Jupiter already appears high in the south as twilight drops its dark blanket over Earth. Shining at magnitude –2.2, it beats every star and falls short only of Venus. The giant world remains visible well into the morning hours, setting around 4:30 A.M. local daylight time April 1 and two hours earlier by month's end. Jupiter resides among the background stars of Cancer, some 5° east-southeast of the Beehive star cluster (M44). Typical 7x50 binoculars will show them both in the same field of view.

Swing a telescope toward Jupiter, and you'll be quickly impressed with the rich detail visible in its cloud tops. The best views come in the early evening when the planet lies highest and its light passes through less of Earth's turbulent atmosphere. The first things you'll see are two parallel dark belts that straddle a brighter zone tracing the planet's 40"-diameter equator. A whole series of light zones and darker belts appears on nights with steady seeing.

Once you've studied Jupiter's atmosphere for a while, turn your attention to the planet's family of moons. Typically Io, Europa, Ganymede, and Callisto show up as bright dots beside the planet and lined up with the jovian equator. Occasionally, however, one or more hide behind Jupiter or transit directly in front of the planet. In the latter case, the moon also drops its shadow onto the planet's cloud tops.

The four moons appear in order of increasing distance (Io through Callisto) to Jupiter's west after midnight April 2/3. This alignment



Europa occults Io the evening of April 8 starting just a minute after the scene shown here. Less than two hours later, Europa eclipses Io.

COMETSEARCH

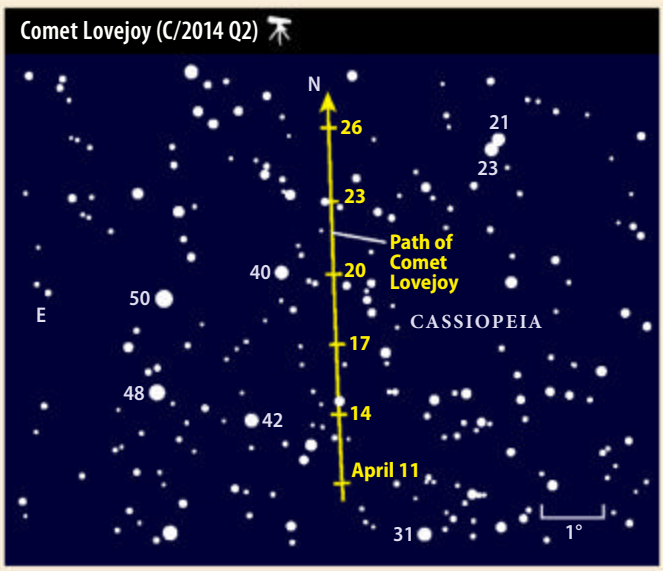
Catch Lovejoy before it's gone

The inner solar system hosts a never-ending parade of periodic comets. The star of these local objects is the infrequent visitor 1P/Halley, but few others give rise to much interest. Luckily, the once-only renegades from the distant Oort Cloud can prove quite entertaining. That's what happened early this year with Comet Lovejoy (C/2014 Q2). This fresh comet brightened unexpectedly to 4th magnitude in January and put on a nice show for anyone who braved the cold.

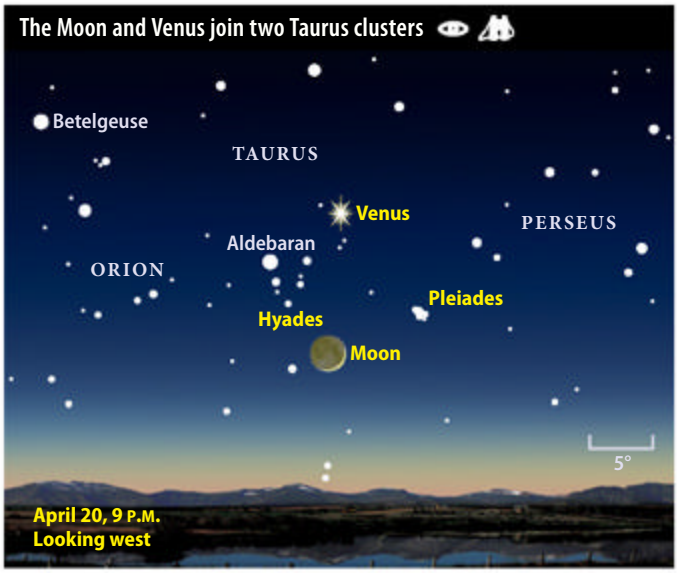
If the more optimistic predictions hold, Comet Lovejoy still might be an 8th-magnitude object in April, but don't be surprised if it's a couple of magnitudes fainter. If it is on the fainter side, you'll need a 6-inch scope under a dark sky to detect the ghostly puffball. Target the time around midmonth when the Moon interferes least. On the plus side, Lovejoy remains visible all night as it drifts in front of Cassiopeia's stars.

The comet's dust output likely is shutting down as the dirty snowball heads away from the Sun, so Lovejoy should appear small and round. Bump the magnification up to 150x or more to see detail. Can you spy the false nucleus — a dot of bright light at the comet's center — through the thinning layers of gas and dust?

Let Comet 88P/Howell serve as a backup plan. This periodic visitor comes closest to the Sun in early April and could grow brighter than 10th magnitude. Howell moves slowly through Aquarius this month, which means it's best placed for more southerly observers. Messier marathoners will understand the challenge right away: Howell lies near M30, typically the toughest object at the end of a long night's observing.



This Oort Cloud visitor continues its northward trek through Cassiopeia in April. The best views come in the Moon's absence around midmonth.



A brilliant planet, several bright stars, and two pretty clusters form a scintillating backdrop for the crescent Moon during evening twilight April 20.

follows an earlier transit of Io and its shadow across the planet's face. The transit begins at 12:04 A.M. EDT followed about an hour later by the shadow.

After Io and its shadow leave Jupiter's disk (at 2:21 A.M. and 3:26 A.M. EDT, respectively), you may notice another alignment in the works. Io passes just 1.4" south of Europa at 4:32 A.M. EDT. And about 90 minutes later, Io eclipses Europa. Observers in western North America can see Europa dim for six minutes starting at 3:06 A.M. PDT.

This eclipse is part of a rare series of mutual events among the four Galilean satellites. They occur when the orbits of the moons turn edge-on to the Sun and Earth, which happens twice during Jupiter's 12-year circuit of the Sun. One moon may pass in front of another (an occultation), or one may cast its shadow on another (an eclipse). The current series will run through August.

A particularly nice pair of mutual events occurs the night of April 8/9. Europa partially occults Io for five minutes starting at 11:51 P.M. EDT. Through a telescope, you will see the two moons merge and then slowly separate.

Later that night, Europa's shadow washes over Io for four minutes beginning at 1:38 A.M. EDT.

The last bright planet rises around 11:30 P.M. local daylight time in early April and two hours sooner by month's end. **Saturn** lies low in the southeast by midnight and appears about a third of the way from the southern horizon to the zenith shortly before morning twilight begins. The planet shines at magnitude 0.2, significantly brighter than any star in its host constellation, Scorpius. Only 1st-magnitude Antares, located 9° southeast of Saturn, comes close.

Saturn moves slowly westward relative to the starry background this month as it approaches opposition and peak visibility in late May. It stands 0.5° north of 4th-magnitude Nu (ν) Scorpii on April 1. By the 30th, it has slid to a position 1.2° north of 2nd-magnitude Beta (β) Sco.

Any telescope will deliver spectacular views of Saturn and its rings. The planet's disk measures 18" across at midmonth and likely will appear bland. But few observers will be able to take their eyes off the stunning rings, which span 41" and tilt 25° to our line of sight.

You'll also see Saturn's biggest and brightest moon, 8th-magnitude Titan, through any scope. You can find it due north of the planet April 2 and 18 and due south April 10 and 26. Three other moons — Tethys, Dione, and Rhea — glow at 10th magnitude and show up through 4-inch and larger instruments. All orbit inside Titan and thus change positions from night to night.

Although **Uranus** and **Neptune** are both morning objects, neither climbs high enough before dawn to merit a look. You're better off waiting a couple of months for better views.

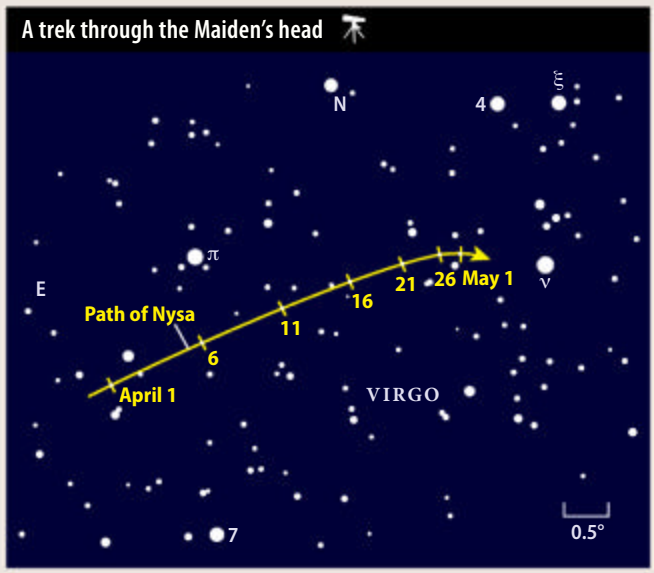
LOCATING**ASTEROIDS**

Nysa plays nice in Virgo the Maiden

Main-belt asteroid 44 Nysa shows up well through a 3-inch telescope from the country or a 6-inch scope from the suburbs in April. The 44-mile-wide space rock lies about halfway up in the southeastern sky during evening hours. You can find the right area easily. Start with the bright tail star of Leo, magnitude 2.1 Denebola, and then drop 8° due south to 4th-magnitude Nu (ν) Virginis. Nysa lies within 5° of Nu all month.

It won't be hard to track the asteroid, but it will require attention to detail. Western Virgo has a sprinkling of stars with a nice range of magnitudes, a real help when trying to locate 10th-magnitude Nysa. On the evenings of April 23–27, a distinctive trapezoid of stars makes a perfect background for seeing the solar system object's night-to-night movement. The asteroid lies out in the open the rest of the month, so it should be easy pickings except when the Moon is nearby through April 4 and after the 27th.

German-French astronomer Hermann Goldschmidt discovered Nysa in May 1857. By the time he was done four years later, Goldschmidt had 14 asteroids to his credit, the record at that time. In Greek mythology, Nysa was the homeland of the Hyades nymphs.



Main-belt asteroid Nysa glows at 10th magnitude in April as it rides high in the southeast evening sky among the background stars of Virgo.

► **Astronauts Steven Smith and John Grunsfeld repair Hubble in December 1999, squeezing in three spacewalks and spending Christmas in orbit before a dash home ahead of the much-feared Y2K computer problems.** NASA/MSFC

SAVING HUBBLE

How astronauts continually reinvented the most important telescope ever. **by Ben Evans**

American astronaut Jeff Hoffman and his wife, Barbara, hosted friends at their home in Houston on New Year's Eve 1993. Three weeks earlier, Hoffman had been part of an ambitious space shuttle mission to repair the Hubble Space Telescope. The guests departed by the end of the evening, and Hoffman was alone in his kitchen, clearing away the dishes. Suddenly, the telephone rang. It was one of his astronomer friends.

"Jeff, hi," came the greeting. "Do you have any champagne left?"

"Yeah, I still have a half-bottle in the refrigerator. Why?"

"Well, crack it open because we've just gotten the first pictures back from Hubble. It works!"

Each time the space shuttle left Hubble, a new observatory and a new chapter of discovery was born. From its launch in April 1990 to the departure of its final human visitors in May 2009, Hubble was reinvented on five occasions. These missions brought new and improved instruments, better computers, a new mechanical heart, hardier gyroscopes, and enhanced solar arrays. Each trip transformed Hubble's capabilities and contributed to its enduring reputation as the most successful telescope ever placed into space.

Kathy Thornton replaces Hubble's solar panel array on STS-61, the first of five shuttle missions to service the space telescope. NASA

However, Hubble wasn't always so clearly destined for success.

When it rose into orbit a quarter-century ago, the telescope boasted five instruments whose imaging range not only encompassed the visible region of the electromagnetic spectrum, but also stretched into the ultraviolet and infrared. Hubble had early troubles with jittery solar arrays. Then, in June 1990, the telescope fell foul to a much-publicized spherical aberration, triggered by a design flaw in its primary mirror that left it unable to focus. NASA was soon the target of late-night talk show hosts and public scorn.

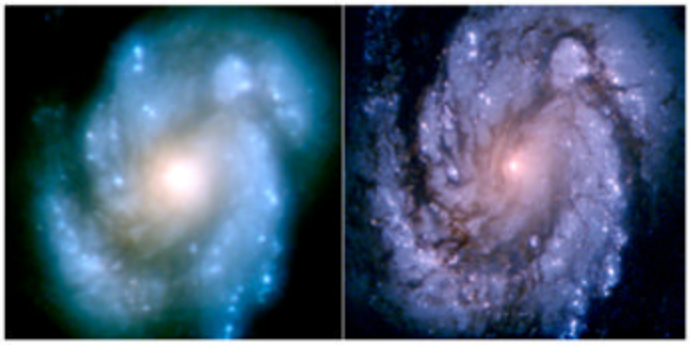
The blurring was worst for the crucial Wide-Field and Planetary Camera (WFPC) and Faint Object Camera. Both instruments suffered in clarity and their ability to acquire detailed images.

The space agency's investigation pinned blame on an instrument called a reflective null corrector, used by manufacturer Perkin-Elmer to aid the accuracy of Hubble's mirror. A lens in the device was incorrectly positioned and guided the polisher to shape a perfectly smooth mirror, but with the wrong curvature. The improper grind specification polished the glass too flat by a mere 1/50 the width of a human hair. It meant that incoming light rays from distant sources couldn't focus at the same point.

A fix would be essential to restore Hubble to its pre-launch billing as the most important advancement in astronomy since the time of Galileo.

The spacecraft's primary mirror could not be changed, so an instrument had to be designed that would let astronauts give Hubble "glasses" while orbiting some 350 miles (560 kilometers) above Earth. The Corrective Optics Space Telescope Axial Replacement (COSTAR) would see 10 small mirrors — each no larger than a coin — placed into the telescope's focal path to correct the effect, restore the potential of the instruments, and bring their performance close to original specifications. In the decades that followed, each new instrument used corrective optics built into its design.

Astronaut Jeff Hoffman holds Hubble's Wide-Field and Planetary Camera during the space telescope's first servicing mission in 1993. NASA



These before-and-after images of spiral galaxy M100 show the extent of Hubble's pre-servicing blur and exactly how well the fix worked. NASA

Hubble's big fix

This wasn't just a repair trip. NASA also made improvements. So when Hubble's first servicing mission eventually launched in December 1993, the astronauts were tasked with installing the upgraded WFPC2 — originally designed as a spare. Before launch, the crew was told that if they installed either COSTAR or WFPC2, astronomers would be "deliriously happy," but with congressional funding for NASA hanging on a knife-edge, this wasn't enough. The mission had to be a full success. NASA Administrator Dan Goldin told the crew that the space agency's future lay in their hands.

Working in two teams, Hoffman and fellow astronauts Story Musgrave, Kathy Thornton, and Tom Akers labored to service Hubble on five spacewalks. The first two excursions replaced a pair of rate-sensing units — whose internal gyroscopes controlled the telescope's orientation — and the two solar arrays.

Ben Evans *is a British spaceflight writer and author of the multi-volume* History of Human Space Exploration, *published by Springer-Praxis.*

The astronauts completed both tasks, though not entirely smoothly. The Sun had warped the gyro compartment doors, and they stubbornly refused to close, threatening Hubble's ability to stay at the proper temperature. Musgrave struggled for some time to close the doors and even tried to push them shut with his helmeted head at one point before the astronauts eventually brought them together. The old solar arrays posed their own issues. One folded up perfectly, but a bent strut prevented the other from doing the same, forcing the crew to dump it overboard.

Next came the installation of WFPC2, which slid perfectly into place and passed an "aliveness" test with flying colors. This cleared the way for the smooth installation of COSTAR, which would bump out an existing instrument, the High Speed Photometer.

The first servicing mission pushed the shuttle's capabilities to its limits. The astronauts faced an unprecedented task, with integrated spacewalking and robotics over five days. The crew brought more than 200 tools into space, from power ratchets to portable work lamps. All told, their spacewalks exceeded 35 hours, and one of them established itself as the second longest in history at that time.

One of those spacewalks also gave Hoffman the fright of his life when he removed Thornton's gloves and noticed her fingers were bright red. His fear that it was blood was quickly calmed by the realization that a chunk of Thornton's red-colored food bar had floated away from her mouth and somehow made its way through her suit, down one of the arms and into the glove. "Not nearly as serious as it looked," Hoffman said in a NASA oral history interview, "but I got quite a shock when I pulled her glove off."

The successful repairs came as a relief for Musgrave, who had been intimately involved in the minute-by-minute planning of the spacewalks for two years. He once joked that his only peace and quiet away from the mission came while sitting in the dentist's chair.

Hubble underwent rigorous testing in the following weeks. NASA configured COSTAR, optically aligned and focused WFPC2, and made test observations. Then, in January 1994, the first stunning images from the rejuvenated telescope were revealed to the world.

But this was just a taste of what would come. Almost two years later, WFPC2 supported 10 days of "deep field" observations, identifying galaxies that dated to within a billion years of the Big Bang. The image was instantly iconic. NASA followed their triumph with Deep Field South in 1998 and then Ultra Deep Field in 2003–2004, which surveyed celestial sources more than 13 billion years old.

New millennium telescope

Even as NASA basked in this success, it launched a second servicing mission in February 1997. The 10-day, five-spacewalk extravaganza by Mark Lee, Steven Smith, Greg Harbaugh, and Joe Tanner

first removed two instruments to replace them with new ones: the Space Telescope Imaging Spectrograph (STIS) and the Near Infrared Camera and Multi-Object Spectrometer (NICMOS).

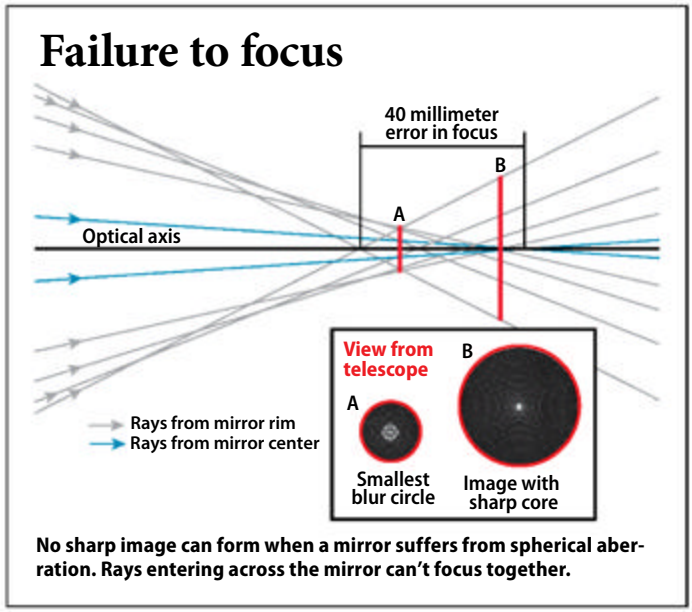
These new arrivals promised to revolutionize Hubble. STIS breaks light up into its component colors, which allows astronomers to study an object's chemical composition, motion, temperature, and density on a level drastically higher than previously possible. In time, STIS would reveal fine details of star birth, help identify supermassive black holes, and investigate the distribution of matter throughout the universe. Meanwhile, NICMOS was designed to shed new light on infrared-light emitters like brown dwarfs.

The first spacewalk of the second servicing mission started later than planned after one of Hubble's solar arrays inadvertently "windmilled," spinning as oxygen escaped from the shuttle's new air lock.

"We coincidentally were trained to recognize an uncommanded slew of the solar arrays," astronaut Steven Hawley, whose job was to operate the robotic arm from inside the shuttle, later explained in an oral history interview. But he and Tanner exchanged nervous glances when they spotted the rapid motion. Both men knew the arrays were not supposed to spin so quickly, and with all cameras focused on the air lock and not Hubble, mission control was unaware of the full extent of the problem.

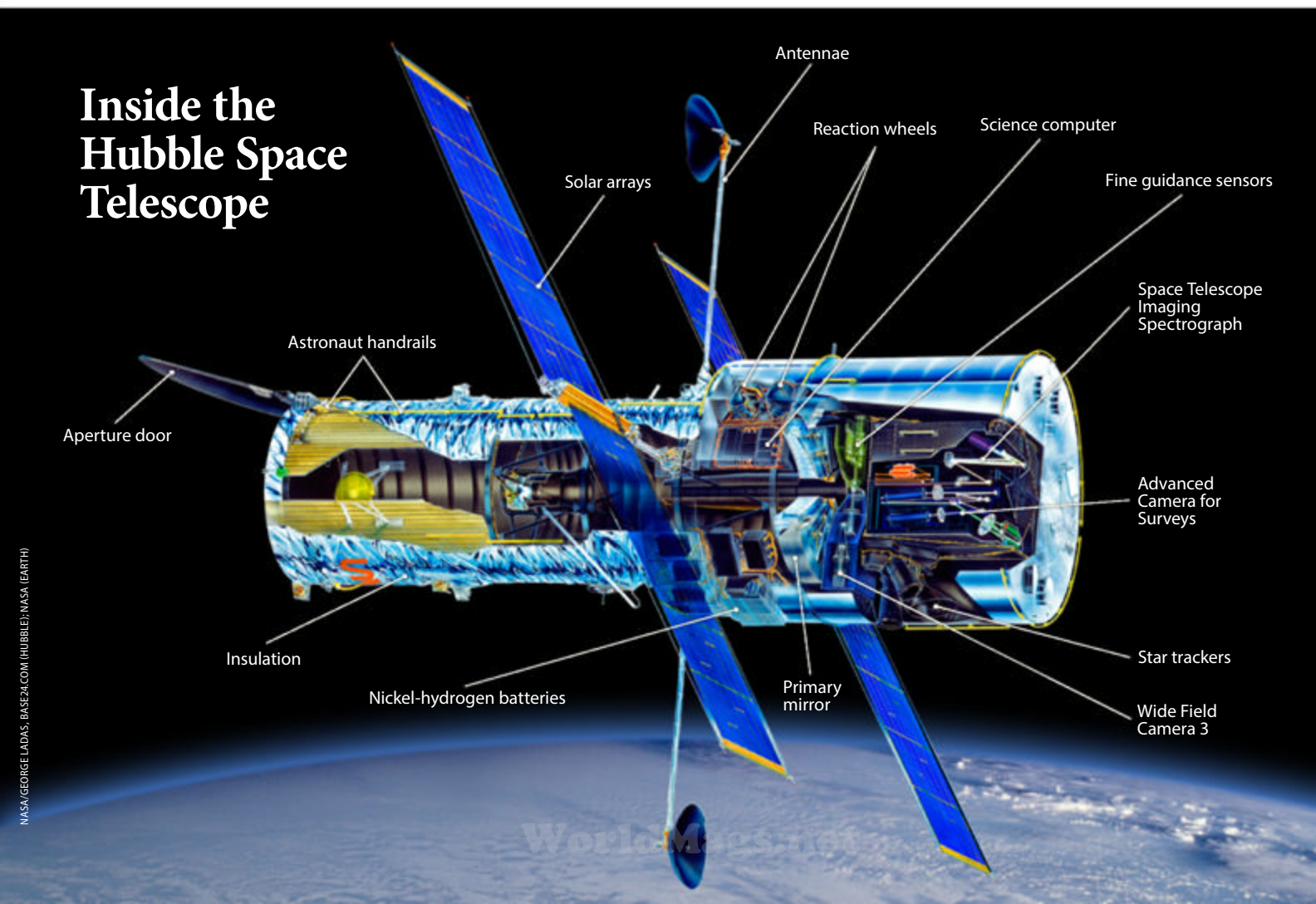
Hawley was convinced that if the event had been captured on television, the spacewalk would have been scrubbed and the entire mission thrown into jeopardy. Fortunately, that was not the case, and Lee and Smith swiftly set to work fitting the new instruments. The team also added technology to enhance Hubble's pointing ability and improve data storage. Their work was lauded at the time by Chief Hubble Scientist Ed Weiler as "the Super Bowl" of spacewalking because it placed the telescope "into a position of having world-class scientific capability well into the 21st century."

The astronauts, however, identified several cracks, a pit-like crater, and evidence of age-related wear on Hubble's thermal insulation. NASA had an extensive overhaul planned for the eventual third mission, but the space agency considered it prudent



No sharp image can form when a mirror suffers from spherical aberration. Rays entering across the mirror can't focus together.

ASTRONOMY: ROEN KELLY



NASA/GEORGE LADAS, BASE24.COM (HUBBLE); NASA (EARTH)

Astronaut Drew Feustel practices working on an underwater mock-up of the Advanced Camera for Surveys in Houston. After its installation in 2002, the instrument became Hubble's workhorse. NASA

to immediately attempt a repair. So mission control added a last-minute fifth spacewalk to the second mission. The astronauts had to use spare pieces of insulation, high-temperature tape, parachute cord, and alligator clips.

Returning safely to Earth, the crew had completed a mission that enhanced Hubble far more than the first servicing mission that overshadowed it. It was profoundly satisfying for the seven astronauts. After two years of training and a flawless execution, Lee declared that he was ready to buy his crew mates a drink. "Up here," he said from orbit, "we've got some orange mango drink and some lemonade, but that's about as stiff as it gets. So I'm ready for a margarita!"

"Hubble 2" was Weiler's description of the telescope when the second servicing mission crew departed. Their work had transformed Hubble from a 1970s spacecraft with 1980s optics into an observatory fit for the new millennium and laden with modern instrumentation.

A wider view

However, in March 1997, NICMOS, Hubble's infrared camera, suffered an electrical short that caused it to lose all of its nitrogen coolant by January 1999, and it was shut down. This proved bitterly disappointing, as the instrument had already shed new light on the changing atmospheres of both Uranus and Neptune.

An instrument repair was planned for the third servicing mission, which NASA broke into two phases. The first, SM-3A, was delayed until December 1999, and by the time the crew reached Hubble, the telescope had lost its fourth of six gyroscopes and been forced to suspend its observations. Hopes to make four spacewalks on SM-3A came to naught as the mission slipped toward the end of 1999 and NASA — worried about the implications of the much-hyped Y2K computer bug — wanted the shuttle back on the ground before the dawn of the new millennium. To achieve this, mission managers shaved two days and one spacewalk from the flight. For only the third time in history, American astronauts spent Christmas in space, a fact that Scott Kelly had taken time to discuss with his 5-year-old daughter.

"I told her that we were going to point the telescope at the North Pole and get a picture of Santa," Kelly said from orbit, according to news reports at the time. "She was all excited and really didn't mind too much her dad being away for Christmas."

Nevertheless, the SM-3A astronauts completed a major overhaul in three spectacular spacewalks, each of which exceeded eight hours in length. "Eight hours was a long time," astronaut John Grunsfeld told a NASA interviewer. "I felt comfortable with that. … But I would say at the end, we were getting pretty darn tired."

The remaining tasks took place on SM-3B, which flew in March 2002. Astronauts removed the last of Hubble's original instruments to make room for the Advanced Camera for Surveys (ACS). The instrument would cover twice as much sky with double the clarity and four times the speed of WFPC2. ACS, with its built-in coronagraph to block out light from stars, would allow astronomers to see their surrounding environments and permit observations of extremely dim exoplanets. Astronauts also hooked up a new experimental cryocooler for NICMOS on the final spacewalk. After three years out of action, the infrared camera was back in service.

Their success was fortuitous, and Grunsfeld, also a professional astronomer, joked that failure would have meant he could never show his face at American Astronomical Society (AAS) meetings.

The Hubble huggers

NASA Administrator Sean O'Keefe canceled a long-planned fifth servicing mission to Hubble in January 2004 following the space shuttle *Columbia* disaster, which claimed the lives of seven astronauts. Grunsfeld, then serving as NASA's chief scientist, took it as a hammer-blow. He considered quitting the space agency.

"As a certified 'Hubble hugger,' that hit me like a two-by-four in the head," he recalled. "I just couldn't believe that we would prematurely make that decision."

The cancellation was also met with criticism from the public and politicians, most notably Senator Barbara Mikulski of Maryland, whose home state plays host to the Space Telescope Science Institute, which operates Hubble. Several months later, in June 2004, O'Keefe explained his decision before an AAS meeting in Denver.

Joe Tanner poses for a picture by fellow astronaut Greg Harbaugh in 1997 during Hubble's second servicing mission. The trip revolutionized Hubble with instruments fit for the new millennium. NASA

Mike Massimino, who flew to Hubble twice, smiles for the camera outside a space shuttle window during Hubble's (seen in the background) final servicing mission in 2009. NASA

"The easy route would have been for us to keep plugging along and hope for the best," he said. "But hope is not a management method we should rely on to keep Hubble operating."

In O'Keefe's mind, he was faced with two undesirable options: fly a shuttle mission without fully complying with the recommendations of the Columbia Accident Investigation Board, or allow Hubble to die prematurely.

His solution was for NASA to explore a robotic mission to Hubble before the end of 2007. Grunsfeld participated extensively in the early planning phase, but ultimately such a mission was too complex.

O'Keefe's resignation from NASA in December 2004 kindled a spark of hope that his successor might approve another shuttle mission, and when Michael Griffin became the new NASA administrator in April 2005, he was far warmer to the idea.

In need of TLC

However, Hubble had other difficulties. STIS, whose impressive accolades would eventually include the first spectrum of an exoplanet's atmosphere, had suffered an electronics failure in August 2004 and was shut down. In addition, Hubble's main camera, ACS, malfunctioned in June 2006 and was later hit by a short circuit in its backup power supply, which put it out of action. This left the aging WFPC2 as the primary visible-light camera.

More trouble was afoot. With the fifth servicing mission finally planned for October 2008, Hubble endured a failure of its Science Instrument Command and Data-Handling Unit in late September. This forced NASA to postpone the astronauts' trip to train the crew on another repair task. Meanwhile, a software upload caused NICMOS' cooling system to operate sporadically.

The final servicing mission took place in May 2009 and involved five spacewalks intended to carry Hubble through at least 2014. Spacewalkers Grunsfeld and Drew Feustel replaced WFPC2 with Wide Field Camera 3 (WFC3). Despite some difficulty removing the old camera's bolts — which required more torque than expected after 16 years in space — they succeeded in pulling it out and installing the telescope's most technologically advanced visible-light instrument.

They also installed the Cosmic Origins Spectrograph, allowing Hubble to perform far- and near-ultraviolet spectroscopy of faint point sources — white dwarfs, cataclysmic variables, and binary stars — and study the origins of large-scale structures in the universe, including the formation of galaxies and the birth of stellar and planetary systems.

As with his two previous visits to Hubble, Grunsfeld took a poignant moment to pat the telescope goodbye, knowing that he would never see it again. But when the shuttle departed, Hubble was left in its best-ever condition, with present estimates suggesting that it may remain functional until 2020.

The work performed by the five shuttle crews between 1993 and 2009 transformed Hubble from a white elephant into a white knight of astronomy. Twenty-eight astronauts supported 23 spacewalks, totaling 166 hours. And of the 10 longest spacewalks ever undertaken, four of them were done while working on Hubble.

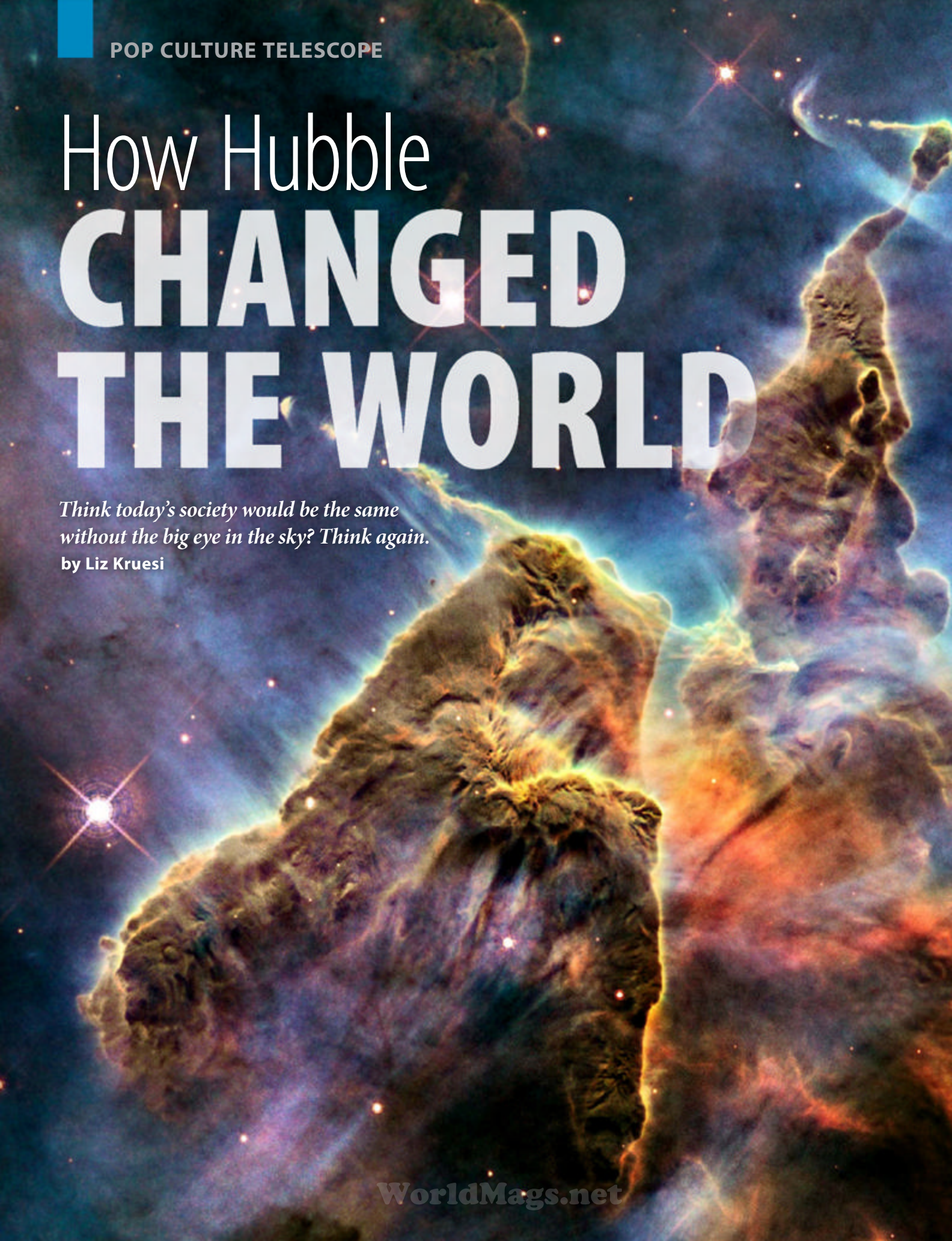
"Three hundred years from now," said Hubble's senior project scientist, David Leckrone, "none of us in all likelihood will be remembered as individuals, but certainly the Hubble Space Telescope will be remembered as a high point in human civilization. That's an awe-inspiring thought and something that motivates us to do our very best for Hubble and for science."

FIND IN-DEPTH COVERAGE OF EACH HUBBLE SERVICING MISSION AT **www.Astronomy.com/toc.**

How Hubble CHANGED THE WORLD

Think today's society would be the same without the big eye in the sky? Think again.

by Liz Kruesi



For the observatory's 20th anniversary, Hubble took this image of the Carina Nebula (NGC 3372).

NASA/ESA/M. LIVIO/THE HUBBLE 20TH ANNIVERSARY TEAM (STScI)

The Hubble Space Telescope — arguably one of the greatest technological achievements ever — was in trouble. Astronauts were to conduct a fifth and final servicing mission of the observatory in 2004, but in January of that year NASA canceled the mission, citing safety concerns. The public, however, wanted to save the great scope. They wrote to astronomers, the space agency, members of Congress, and the media to reinstate the mission. And it worked. In 2006, NASA announced that it would send astronauts to service Hubble one last time.

The telescope clearly has had a profound impact during its quarter-century of observations — on science and exploration, of course, but also on a much wider audience. Other scientific facilities have tried to emulate Hubble's formula, but none has come close to the impact this telescope has had. A combination of attributes makes Hubble an immensely influential project. Its incredible views of the cosmos, which are both gorgeous and real, bring the excitement of discovery to households across the globe. Its images have inspired artists in many mediums to produce musical compositions, paintings, and choreography. But another aspect — the direct human interaction and involvement in the mission — helps hold Hubble's science in the public mind.

The early years

It was a different story in 1990. When scientists saw Hubble's first images in May of that year, they were disappointed and frustrated. Technicians had ground and polished the telescope's 2.4-meter mirror to the wrong shape, so it couldn't focus the light it collected into crisp points; Hubble had fuzzy vision. Politicians ridiculed the project, comedians made it the brunt of jokes, and the U.S. public thought of it as a costly mistake. People were angry — after all, it was a primarily federally funded mission, so taxpayers had footed much of the bill, some $2.5 billion at that point.

But scientists and engineers had developed Hubble to be serviced. And that aspect of the mission is what saved it.

NASA and the Space Telescope Science Institute (STScI), which operates Hubble, faced the problem and found a solution in just three years. In December 1993, astronauts aboard the space shuttle *Endeavour* installed two instruments on the telescope: a new camera and the Corrective Optics Space Telescope Axial Replacement (COSTAR) that acted like eyeglasses.

The "Pillars of Creation," a star-forming region in the Eagle Nebula (M16), is probably the Hubble Space Telescope's most iconic image. NASA/ESA/STScI/JEFF HESTER AND PAUL SCOWEN (ARIZONA STATE UNIVERSITY)

The new lenses worked. Hubble could resolve details never before imaged, like the wisps of gas around baby stars and suns in distant galaxies.

Since the repairs, the telescope has contributed to countless scientific discoveries and even a Nobel Prize in physics (see "Hubble's top seven science discoveries" on p. 28). On a more public level, teachers post Hubble's spectacular images in classrooms, and outreach materials from the project are part of education curricula throughout the United States, explains STScI's Kenneth Sembach, who began working with the telescope when it launched.

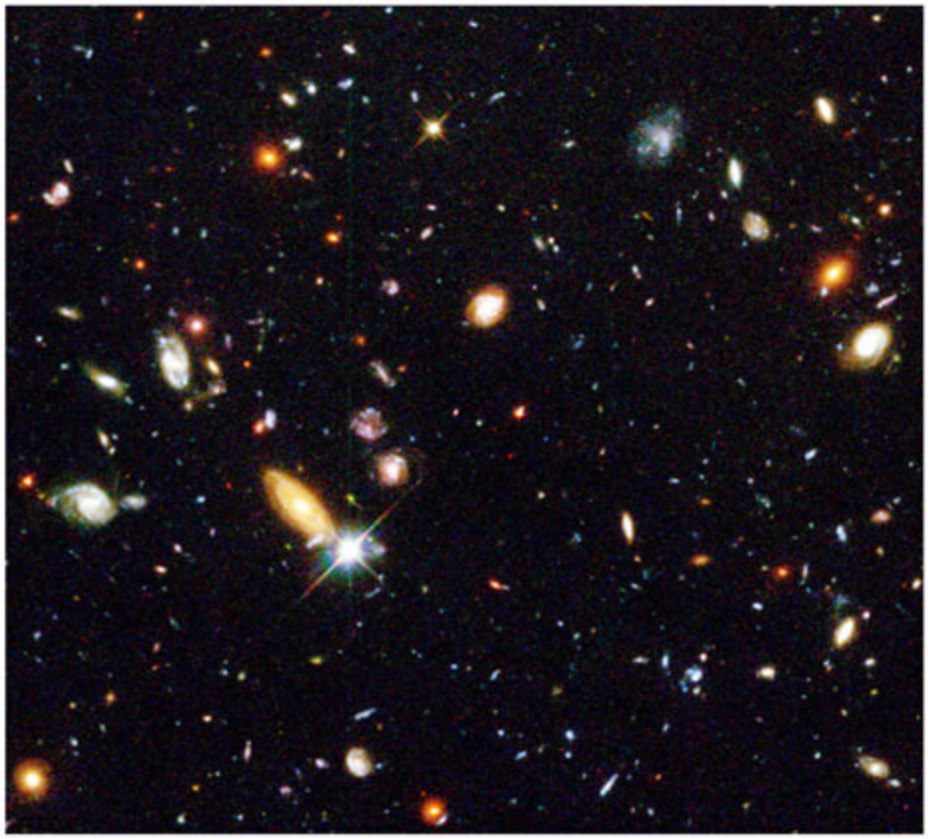
A familiar tone

Hubble's pictures strike a chord with people. Of course, they are gorgeous, which is no mistake. When the telescope images a celestial object, it does so through filters, each of which allows specific wavelengths to pass through. But Hubble collects more than visible light. Its detectors also can record ultraviolet and infrared radiation. For those images, scientists assign the colors red, green, or blue to each filter. The end product is a false-color rendition of the target, but one that effectively conveys its essence while retaining the valuable scientific data.

Many of the images look like works of art, but what's important, says STScI's Mario Livio, "is that as beautiful as these things are, they actually exist somewhere in our universe." The laws of physics and chemistry have created these incredible structures, and Hubble has revealed them.

Hubble images collected in the mid-1990s inspired Astronomy *Contributing Editor* **Liz Kruesi** *to study physics to understand the science responsible for the structures in those gorgeous shots.*

On December 18, 2012, scientists at the Space Telescope Science Institute, realizing that the public loves Hubble's images, released this one they called "A Cosmic Holiday Ornament." The image shows planetary nebula NGC 5189. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)



This image, dubbed the Hubble Deep Field, captured the imagination of scientists and the public when the space agency released it in early 1996. R. WILLIAMS (STScI)/THE HUBBLE DEEP FIELD TEAM/NASA

Hubble took this image of star-forming region NGC 3324 to celebrate its 10th anniversary in space. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)/N. SMITH (UNIV. OF CALIFORNIA, BERKELEY)

Probably the most iconic image from Hubble is its portrait of the "Pillars of Creation" in the Eagle Nebula (M16), which astronomers released in November 1995 (see p. 26). Those three columns of gas and dust, shaped by the radiation and particle winds of newborn stars, fill the field of view. "That image, the way it was framed was brilliant," says Sembach. "It fit within that chevron shape of the camera that was on board at the time so beautifully, and it was orientated in a way that you get the full pillar effect."

The image shows depth that many photographs of celestial objects can't capture and gives the pillars three-dimensionality. They look like something you could touch, and that quality helps draw the public in.

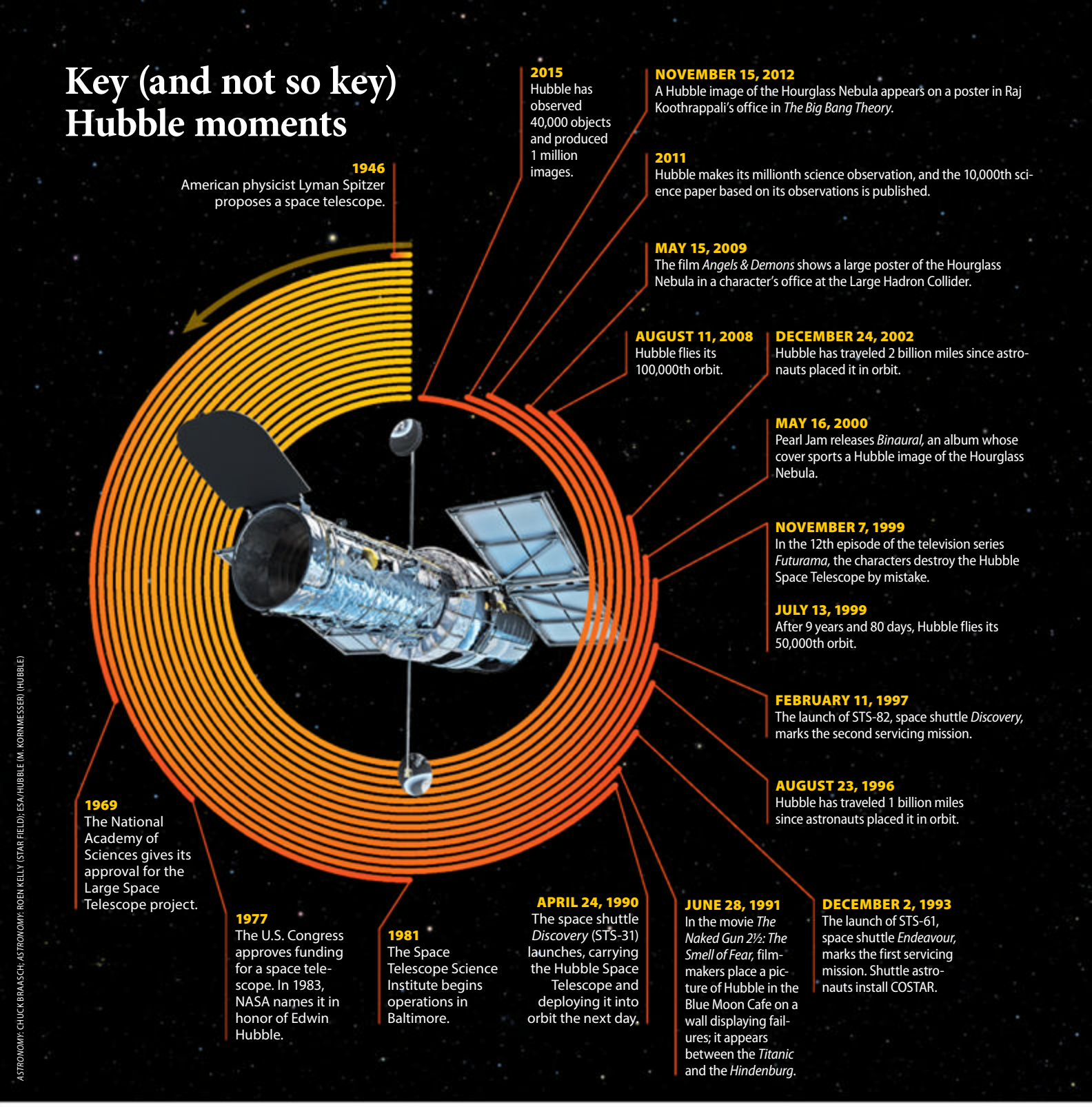
But that image struck a chord with people for another reason, too. The colors scientists chose for the composition are familiar. The pillars resemble structures on Earth, which makes this image relatable.

When STScI released the image, the accompanying text drew the following comparison: "The pillars are in some ways akin to buttes in the desert, where basalt and other dense rock have protected a region from erosion, while the surrounding landscape has been worn away over millennia." And although the scales of these objects are vastly different — earthly rock formations can extend from a few to hundreds of feet, while the cosmic pillars are a few light-years, or trillions of miles, long — the public embraced the connection.

Art historians also have extended the comparison. Elizabeth Kessler of Stanford University, for example, has studied many Hubble images and written a book about the artistic choices that researchers have used in the photographs. She looked at how scientists frame objects and what colors they assign to different filters. While astronomers designate specific "colors to communicate physical attributes of the nebulae or galaxies, different temperatures, or the locations of different kinds of gases, those same colors often also suggest a kind of earthly landscape," says Kessler.

Hubble images are ethereal and eerie but at the same time familiar. "I think the images themselves walk this really careful line between looking very alien and strange and exciting," Kessler says, "and yet they also remind us of places that have been explored and understood here on Earth."

For researchers, Hubble satisfies a desire to explore, whether by imaging a nearby world or investigating galaxies billions of light-years away. The telescope has imaged dust storms on Mars, discovered disks of material around young stars, and seen quasars across the universe. And through all the research, Hubble has brought the public along for the ride. "It has taken the excitement that the scientists usually feel with new discoveries and brought it to homes of nonscientists," says Livio.



ASTRONOMY: CHUCK BRAASCH; ASTRONOMY: ROEN KELLY (STAR FIELD); ESA/HUBBLE (M. KORNMESSER) (HUBBLE)

The intersection with art

While scientifically important, Hubble's images are works of art and have appeared in exhibits in places like the Walters Art Museum in Baltimore and the Istituto Veneto di Scienze, Lettere ed Arti in the Palazzo Loredan in Venice, Italy. Even artists of different mediums have drawn inspiration from the telescope.

Choreographer Liz Lerman, once the recipient of a MacArthur "genius grant," created a contemporary dance titled *The Matter of Origins*, in which the first half of the piece focused on the physics of the universe. Lerman used images from Hubble, data from particle accelerators, and scientific equations throughout.

German artist Tim Otto Roth created two pieces incorporating light and sound that he based on Hubble's investigation of the universe. His *From the Distant Past* (see p. 55) showed at the American Museum of Natural History in New York City and at the Maryland Science Center in Baltimore in 2010; his *Heaven's Carousel* showed at Accademia dei Lincei in Rome in 2014.

Composer Paola Prestini recently worked with Livio on a contemporary classical multimedia composition that mixes an orchestral arrangement, vocalists, spoken word, and film — all to connect human life to the lives of stars. (The collaboration also includes a librettist, Royce

To commemorate Hubble's 100,000th orbit, astronomers released this image of a nebula near star cluster NGC 2074. NASA/ESA/M. LIVIO (STScI)

FROM THE CLASSROOM TO POP CULTURE

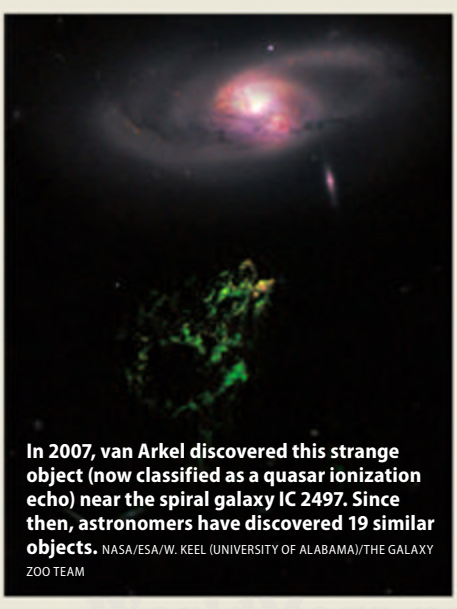
Editor's note: The Hubble Space Telescope has catapulted few people into pop culture as fast as Hanny van Arkel. So, Astronomy *invited the Dutch schoolteacher to tell her story here.*

Hanny van Arkel was a Dutch schoolteacher prior to discovering her voorwerp (Dutch for "object"). The media frenzy carried her into the heart of pop culture. HANNY VAN ARKEL

Back in 2007, I signed up for the online citizen science project Galaxy Zoo. Chris Lintott had invited the public to help him classify galaxies acquired with the Sloan Digital Sky Survey using a home computer interface. I had heard about this through Queen guitarist and astrophysicist Brian May, who mentioned it on his website. That my passion for music would one day lead me to become a somewhat well-known amateur astronomer was something I never could have guessed.

In one of the pictures, I spotted a remarkable looking blotch. I sent Lintott an email to ask what it was. Lintott then invited me on the team to investigate using follow-up images taken with Hubble. I certainly learned a lot — not only about the object, but about the process, too. Meanwhile, the press got interested and I became a spokesperson, giving lectures across the world.

There's also a comic out about my story, and Lintott and May mention Hanny's Voorwerp (Hanny's object) in their latest book. I am grateful for these experiences, and I feel fortunate to be able to tell the world that it is a lot of fun to be an amateur astronomer. — *Hanny van Arkel*



In 2007, van Arkel discovered this strange object (now classified as a quasar ionization echo) near the spiral galaxy IC 2497. Since then, astronomers have discovered 19 similar objects. NASA/ESA/W. KEEL (UNIVERSITY OF ALABAMA)/THE GALAXY ZOO TEAM

Vavrek, and filmmaker Carmen Kordas.) The *Hubble Cantata* "fuses the story of the struggle associated with human life with the continuous cosmic battle that stars have to conduct against the universal force of gravity," says Prestini.

"The structure of the work includes movements and songs by the soloist, with interjecting interludes that include the choir and an electronic tapestry made of [Livio's] voice, imagined space sounds, plus the improvising of a very special violin soloist," she adds. "The Hubble images appear during the interludes and take on a life of their own: They contort, grow, and fuse with physical life — reminding us of where life originated and where we might be all headed."

The *Hubble Cantata* debuted July 2013 and was performed again in November of that year. The collaboration is expanding the cantata, says Prestini, and the full-length version should be complete for the telescope's 25th anniversary.

While these examples incorporate the beauty of Hubble photographs, artistic messages, and science, the telescope's cosmic imagery also has been used in more commercial instances, like album covers, stamps, and clothing — because, heck, why not wear a dress, swimsuit, or tie adorned with Hubble images?

Hubble house calls

But it's not just about the images. Another major reason the telescope has had such an impact is the "human involvement in the servicing of Hubble over the years," says Sembach. "It's like sending a doctor on a house call. The telescope is sick; somebody goes up to fix it."

This month, Hubble turns 25, and luck isn't what got the telescope to this point. Scientists and engineers planned the mission well: place the telescope into near-Earth orbit, at a distance where the space shuttle can reach it, and then have astronauts service it. During the five servicing missions, astronauts have upgraded the electronics, replaced the telescope's gyroscopes (which are crucial for pointing the observatory at celestial targets), and installed new scientific instruments.

Humans have essentially created a new observatory during each servicing mission, says Sembach. And that, he adds, "really helps to keep it at the cutting edge of what scientists are working on. It helps it to actually push that edge."

It also helps that humans — including the public — got involved to fight a vocal

public battle to convince NASA to send up the final servicing mission. (For more on this, see "Saving Hubble" on p. 44.)

The astronomical culture

In addition to Hubble's tremendous impact on the public's interest in science, the project has helped drive research and collaboration in the professional astronomy community. Just a quick look at statistics compiled by the American Institute of Physics shows a drastic increase in the number of students studying astronomy over the past three decades.

In the mid-1980s, there were some 700 students enrolled in U.S. graduate astronomy programs; by 2012, the number was up to roughly 1,100. Three decades ago, universities awarded between 70 and 80 doctorates per year; in 2012, the number had doubled to about 150.

On average, some 40 doctoral research projects each year are based on Hubble data, says Sembach. "The pool of postdoctoral fellows in astronomy is now two or three times bigger than it was just 20 years ago," says Meg Urry, the current president of the American Astronomical Society. The students who were in their formative educational years — elementary, middle, and high school — when Hubble began sending back its incredible images and contributing to major discoveries are now early-career professors or postdoctoral researchers.

A Hubble image of the Hourglass Nebula appears on the cover of the 2000 CD *Binaural* by the rock band Pearl Jam. California Guitar Trio's 2010 CD, *Andromeda*, uses a Hubble image on its cover.

TIM OTTO ROTH, IMACHINATION PROJECTS (WWW.IMACHINATION.NET/DISTANTPAST)

Artist Tim Otto Roth's *From the Distant Past* translates spectra of distant objects that Hubble captured into green animated laser projections on prominent facades in public spaces, as for instance at the Maryland Science Center in Baltimore in autumn 2011.

"Astronomy departments have grown, and, equally important, physics departments have been adding astronomers to their faculty," Urry says. The statistics are even more telling when looking at undergraduate degrees: In the mid-1980s, about 140 students earned a bachelor's degree in astronomy, but in 2012, two and a half times as many graduates earned an astronomy bachelor's.

Hubble also has influenced how and when astronomy projects release their data. When Robert Williams, then director of STScI, and his team collected the individual frames for the Hubble Deep Field (HDF) composite in 1995, they processed and released the data in two weeks. Scientists who use federally funded astronomical instruments have one year to keep the data to themselves for analysis. But the HDF scientists "thought for a facility like Hubble, which was very expensive and paid for by the public, that we owed it to the community, both the professional and the public, to make the important HDF data available immediately," says Williams.

They helped change the culture of astronomical observing. And now, when undergoing the peer review process to obtain telescope time, "the panelists who review especially larger proposals tend to favor groups who propose and promise that they will make the data available immediately," he adds. Future projects, like the Large Synoptic Survey Telescope, set to come online within a decade, will follow this trend and make all data available immediately.

For Hubble's 20th anniversary, the European Space Agency conducted a Hubble Pop Culture Contest. ESA

A long life

While other space observatories have contributed to major astronomical discoveries, none has remained operational for as long as Hubble. In that time, it has clearly ingrained itself in the minds of the public, popular culture, and the media.

Williams credits many of Hubble's later years to the public who fought alongside astronomers to save it a decade ago. "The telescope has been working perfectly since," he says. Scientists expect to operate Hubble until at least 2020, but "you never know how long it will last," says Williams. "Space is a hostile environment."

Whenever that fateful day arrives, says Sembach, "A lot of us are going to feel like we've lost a family member." It's likely scientists involved in the mission won't be the only ones to feel the loss.

LEARN HOW SCIENTISTS PRODUCE HUBBLE'S ICONIC IMAGERY AT **www.Astronomy.com/toc.**

25 YEARS of dazzling images

The space telescope's extraordinary vision has revealed star clusters, nebulae, and galaxies in detail no one could have imagined.

by Richard Talcott

The Eagle Nebula. Scientists recently targeted one of Hubble's iconic subjects — the Eagle Nebula's (M16) "Pillars of Creation" — with the space telescope's Wide Field Camera 3 (WFC3). Inset: In the near-infrared, WFC3 shows the pillars silhouetted against background stars. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

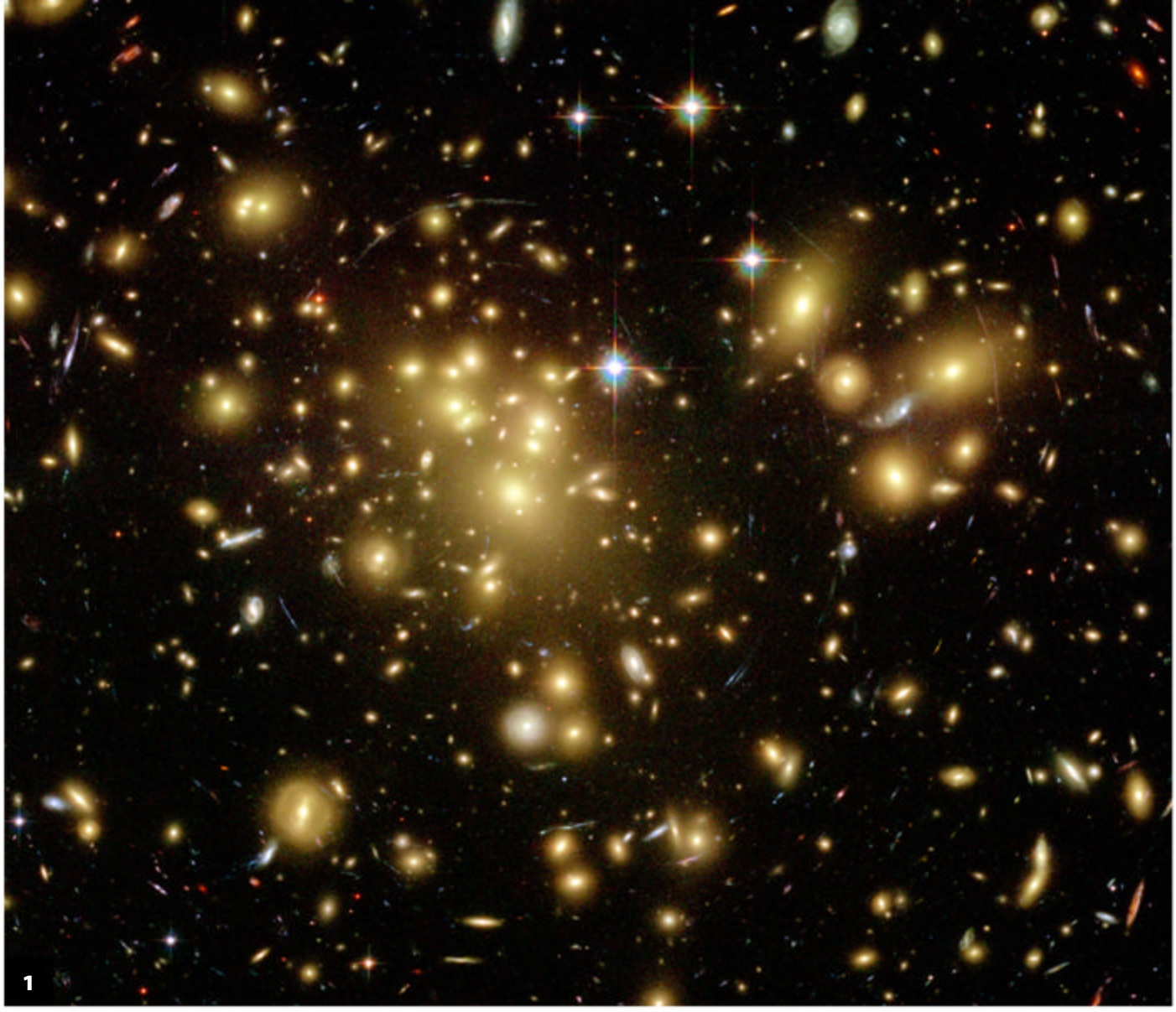
The calendar says a quarter-century has passed since the space shuttle *Discovery* lifted its cargo of dreams into low Earth orbit. Elevated above the distorting effects of our planet's turbulent atmosphere, the school-bus-sized Hubble Space Telescope promised clearer views of the night sky than humans had ever witnessed.

Sure there were glitches, most notably a primary mirror ground to the wrong shape and equipment that inevitably wore down under the harsh conditions of space, but NASA anticipated problems. A series of five servicing missions not only restored Hubble to its original specifications but also rebuilt the observatory into a 21st-century science machine. With new cameras and spectrographs operating nearly 24/7, much of what Hubble does today could hardly be dreamed of in 1990.

Just how much has Hubble accomplished during its 3-billion-mile (5 billion kilometers) journey around Earth? Scientists have published more than 12,000 papers in peer-reviewed journals using Hubble data. And not all of that science has come from new observations — researchers routinely plumb the Hubble archives, which currently hold more than 100 terabytes of data.

But to most of us, Hubble's greatest contribution has been its images, which span the cosmos from next door (the Moon) to the universe's earliest galaxies. In its 25 years, Hubble has snapped more than 1 million images of nearly 40,000 objects. The 28 we show here are the cream of the crop, though, truth be told, it would be easy to pick an entirely different set and say the same thing.

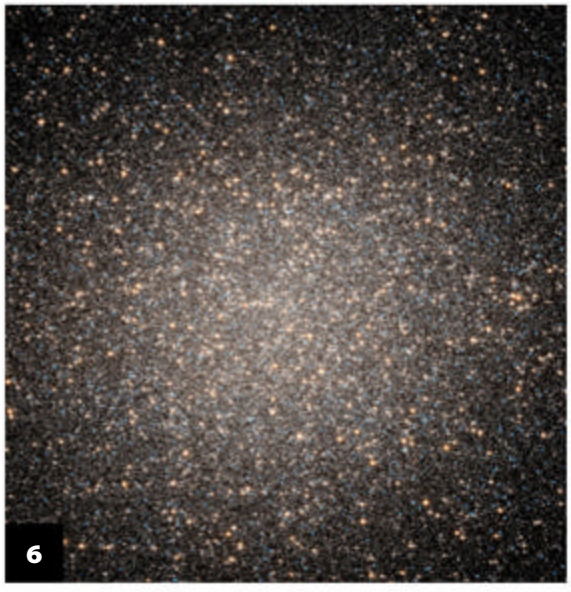
Senior Editor **Richard Talcott** *has covered Hubble's trials and triumphs throughout the observatory's 25 years in space.*



1. Abell 1689. Scientists estimate that Abell 1689 contains thousands of galaxies and holds up to 500 trillion times the Sun's mass. All that matter warps surrounding space, distorting and magnifying light from more distant galaxies. NASA/ESA/N. BENITEZ AND H. FORD (JHU)/T. BROADHURST (THE HEBREW UNIVERSITY)/M. CLAMPIN AND G. HARTIG (STScI)/G. ILLINGWORTH (UCSC/LO)/THE ACS SCIENCE TEAM

2. NGC 1300. Like the Milky Way, NGC 1300 is a barred spiral galaxy that spans a bit more than 100,000 light-years. In such galaxies, spiral arms wind out from the ends of a star-filled bar. NASA/ESA/ THE HUBBLE HERITAGE TEAM (STScI/AURA)

3. The Cone Nebula. Massive stars off the top of this image emit ultraviolet radiation that erodes the edges of the Cone Nebula (NGC 2264). This process liberates gas, and the ultraviolet light then excites this hydrogen-rich material, causing it to glow with a characteristic red color. NASA/ESA/H. FORD (JHU)/G. ILLINGWORTH (UCSC/LO)/M. CLAMPIN AND G. HARTIG (STScI)/THE ACS SCIENCE TEAM

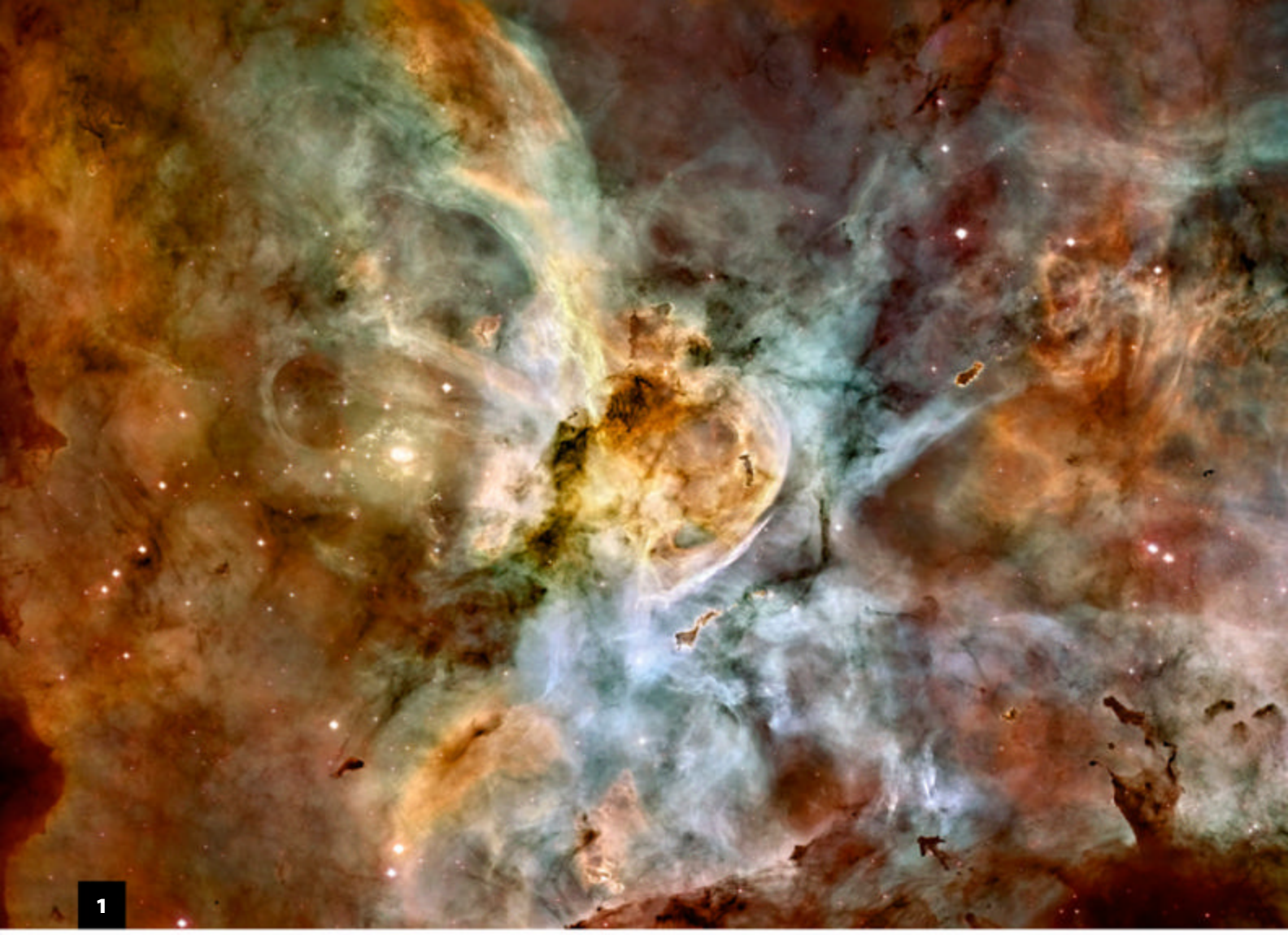


4. The Horsehead Nebula. In visible light, this cloud of cold gas and dust appears dark against bright emission. But at the near-infrared wavelengths captured here, the nebula glows as its gas reradiates energy it absorbs from embedded young stars. ALL IMAGES THIS PAGE: NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

5. V838 Monocerotis. In January 2002, the star seen at center flared to become one of our galaxy's most luminous. This view from two years later captures surrounding dust shells lit up by the eruption.

6. Omega Centauri. The Milky Way's largest globular star cluster, Omega Centauri (NGC 5139), holds 10 million stars in a sphere some 150 light-years across.

7. Supernova remnant N49. Hubble lets astronomers probe objects in nearby galaxies with a clarity previously impossible. Case in point: these splintered remains of a massive star that exploded 160,000 light-years from Earth in the Large Magellanic Cloud.

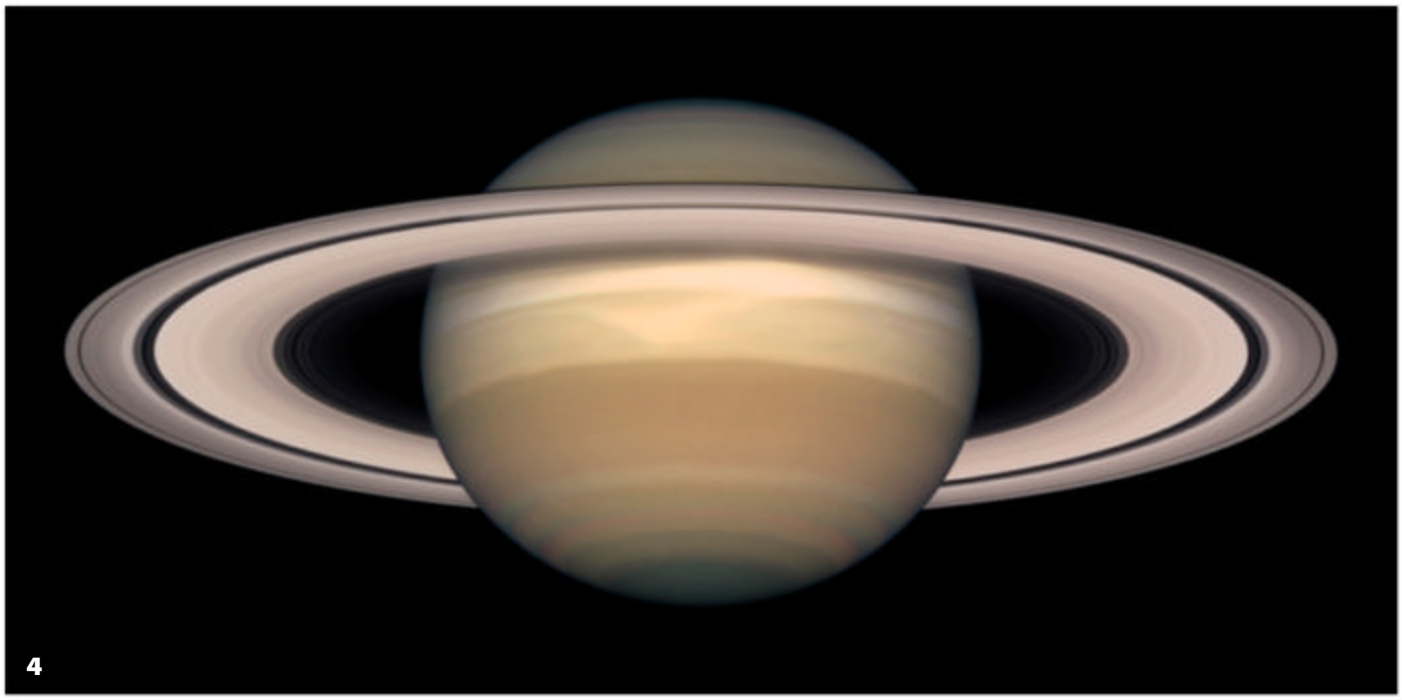


1. The Carina Nebula. One of the Milky Way's premier star factories is the Carina Nebula (NGC 3372), which came to life about 3 million years ago when stars first ignited in a cloud of molecular hydrogen. Ultraviolet radiation and stellar winds from these stars carved out an expanding bubble of hot gas. Now, as this gas plows into surrounding walls of cold hydrogen, it is triggering a second wave of star birth. NASA/ESA/N. SMITH (UCB)/THE HUBBLE HERITAGE TEAM (STScI/AURA)

2. The Cigar Galaxy. Fiery plumes of glowing hydrogen erupt from the central regions of this starburst galaxy, also known as M82. Colliding gas clouds there give birth to stars, many of which reside in giant clusters, at a rate 10 times higher than in the entire Milky Way. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

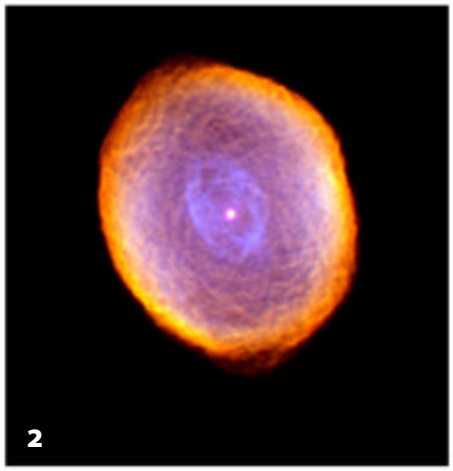
3. Arp 273. When spiral galaxies interact, tidal forces warp their normal stately shapes. In this pair, the spiral arms of the top galaxy have been stretched and distorted. The bright blue star clusters at top reflect a firestorm of star formation initiated by the encounter. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

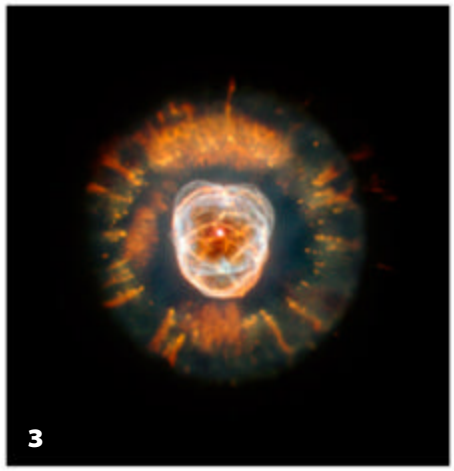
4. Saturn. Although Hubble spends most of its time viewing distant stars, nebulae, and galaxies, it devotes quality time to the solar system. Saturn's cloud tops and rings are a frequent target. During its 25 years in space, Hubble has tracked the planet through 85 percent of its orbit. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)



1

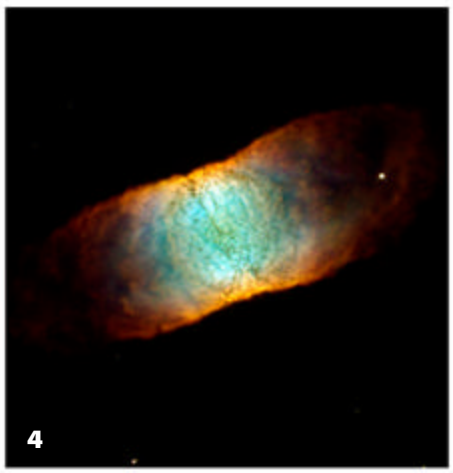
1. The Helix Nebula. The intricate shapes of planetary nebulae, like the Helix Nebula (NGC 7293) and the others on this spread, make them among Hubble's most dramatic subjects. These objects are the death throes of Sun-like stars, which puff off their outer layers — often several times — when they exhaust their nuclear fuel. NASA/NOAO/ESA/THE HUBBLE HELIX NEBULA TEAM/M. MEIXNER (STScI)/T. A. RECTOR (NRAO)

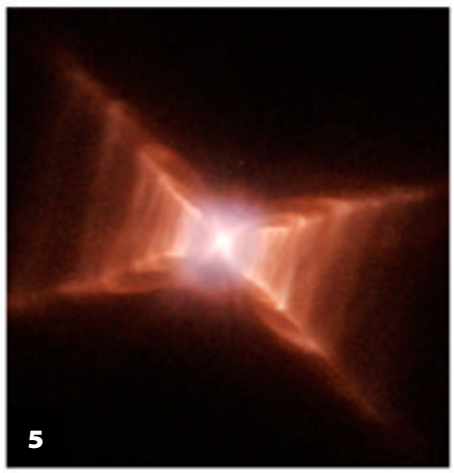




2. The Spirograph Nebula. The progenitor star of the Spirograph Nebula (IC 418) cast off its outer layers multiple times, filling the planetary's interior with lots of gas. A white dwarf stands out at the heart of the nebula; such stars energize the nebula's gas and cause it to glow. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

3. The Eskimo Nebula. Astronomers nicknamed this planetary the Eskimo Nebula (NGC 2392) because it looks like a human face surrounded by a parka hood through earthbound telescopes. Hubble resolves the parka's "fur" into myriad streamers of gas that resemble giant comets pointing toward the nebula's center. NASA/A. FRUCHTER AND THE ERO TEAM (STScI)





4. The Retina Nebula. An irregular web of dark dust lanes crisscrosses the central regions of the Retina Nebula (IC 4406). Each of the lanes is roughly twice the size of Pluto's orbit around the Sun. This image has been color-coded so hydrogen appears green, oxygen blue, and nitrogen red. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

5. The Red Rectangle. This object hasn't quite reached the planetary nebula stage. Although the dying star at center has ejected much of its outer atmosphere, it has not yet evolved into a white dwarf. Cool dust, which forms the unique features that look like the rungs on a ladder, reflects starlight. NASA/ESA/H. VAN WINCKEL (CATHOLIC UNIVERSITY OF LEUVEN)/M. COHEN (UCB)

6. The Blinking Planetary. Through amateur telescopes, the Blinking Planetary's (NGC 6826) central white dwarf is so bright that it overwhelms the nebula when viewed directly; the nebula "blinks on" when looking to the side. Hubble shows both clearly, along with two red patches near the nebula's edge. NASA/ESA/B. BALICK AND J. ALEXANDER (U. OF WASHINGTON)/A. HAJIAN (U.S. NAVAL OBSERVATORY)/Y. TERZIAN (CORNELL U.)/M. PERINOTTO (U. OF FLORENCE)/P. PATRIARCHI (ARCETRI OBSERVATORY)

7. The Cat's Eye Nebula. Mass loss in aging stars doesn't always follow one pattern. The Cat's Eye Nebula (NGC 6543) shows at least 11 concentric shells surrounding its central white dwarf, each one ejected at 1,500-year intervals. But about 1,000 years ago, the process changed and forged the bright irregular shells on the inside. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

8. The Ant Nebula. Astronomers aren't sure what causes the narrow "waist" that lies between the two glowing lobes of the Ant Nebula, so called for its resemblance to the common insect. Some suspect an unseen companion sweeps material out of this region, while others think magnetic fields do the job. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

1. Star cluster NGC 602. The hot young stars in NGC 602 have carved out a cavity in a surrounding cloud of gas and dust located on the outskirts of the Milky Way's satellite galaxy, the Small Magellanic Cloud. This image combines Hubble observations (shown as red, green, and blue) with X-ray (purple) and infrared (red) data. NASA/ESA/CXC AND THE U. OF POTSDAM/JPL-CALTECH/STScI

2. The Veil Nebula. Some 5,000 to 10,000 years ago, our ancestors likely saw a massive star explode in the constellation Cygnus. The star's tattered remains now span 3°, or roughly 75 light-years. This close-up Hubble image shows a tiny part of it, barely 1-light-year across, at the Veil Nebula's northwestern edge. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

3. Arp 142. Tidal forces unleashed by the gravity of elliptical galaxy NGC 2937 (bottom) distort the previously normal spiral NGC 2936 just above it. The spiral's arms and dark dust lanes now splay haphazardly across that galaxy's disturbed disk, while blue knots trace the sites of ongoing star formation. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

4. The Sombrero Galaxy. This giant spiral galaxy lies about 35 million light-years from Earth on the edge of the Virgo Cluster of galaxies. The Sombrero (M104) looks like a traditional Mexican hat because we view its dusty disk from just 6° north of the galaxy's equator. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

5. Sharpless 2-106. This hourglass-shaped stellar nursery spans 2 light-years and lies less than 1° from the Milky Way's plane in the constellation Cygnus. The young star just below center (where the bluish lobes come together) sculpts the surrounding nebula's intricate shape. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

6. The Antennae. Galaxies NGC 4038 and NGC 4039 are merging. This cosmic collision is giving birth to billions of new stars, most of which belong to bright blue star clusters. The large yellowish globes at upper right and lower left are the cores of the original galaxies. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

The Orion Nebula. Hubble gives astronomers ringside seats to watch stars come to life in the Orion Nebula (M42). This dense cloud of gas, dust, and young stars lies just 1,500 light-years from Earth. The hottest, most massive stars already have emerged from their natal cocoons. NASA/ESA/M. ROBBERTO (STScI/ESA)/ THE HUBBLE SPACE TELESCOPE ORION TREASURY PROJECT TEAM

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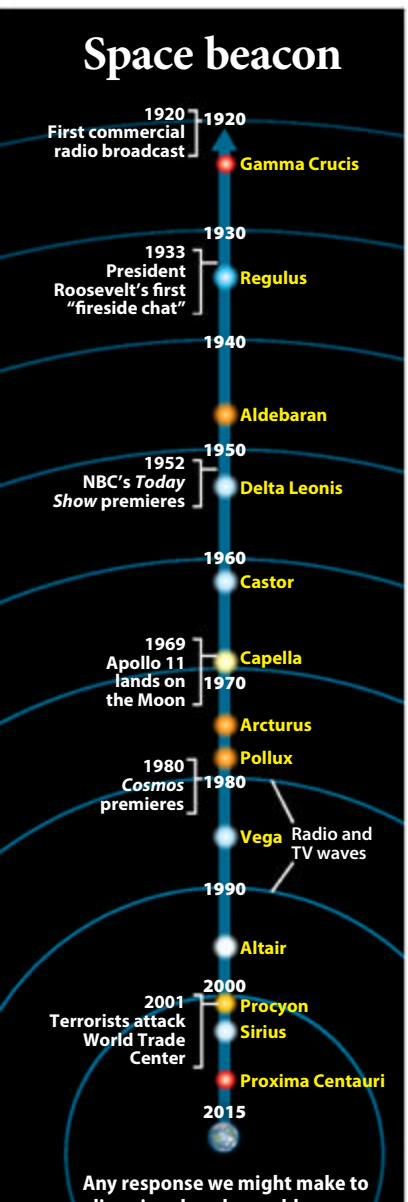
ALIEN AIRWAVES

Q: THE SETI INSTITUTE IS AFTER ALIEN SIGNALS. ASSUMING ANOTHER WORLD IS BEAMING A 1-MILLION-WATT RADIO SIGNAL IN OUR DIRECTION, HOW FAR AWAY CAN THAT SOURCE BE BEFORE THE SIGNAL IS LOST IN INTERGALACTIC NOISE?

Don Schmidt, *Oro Valley, Arizona*



Any response we might make to alien signals only would accompany the TV, radio, and radar signals that have broadcasted our existence for decades.

ASTRONOMY: ROEN KELLY

A: Many people assume that radio signals only can travel a limited distance before they are, like the Robinson family, lost in space. They believe there's a range beyond which transmissions reach an intensity lower than background static and therefore become thoroughly undetectable.

It's not true. Yes, radio signals diminish in intensity with the square of the distance just as light does (after all, radio and light are both electromagnetic waves). But nonetheless, if you have a large enough antenna and adequate observing time, you can tease out a signal no matter how far the transmitter. The background noise simply averages out with time, while the signal relentlessly builds up. Astrophotographers know this well. With a big enough telescope and a long enough exposure, they can successfully image objects at great distances.

The best SETI experiments can detect narrowband radio signals — those confined to a tiny range of frequencies — at a sensitivity level of 10^{-25} watts per square meter with a few minutes of "exposure time." That's 0.1 trillionth of a trillionth of a watt falling on each square meter of the antenna, which is stunningly sensitive.

The Chinese spacecraft Chang'e 5-T1 returned this image of Earth and the farside of the Moon as part of an engineering test trip for a future lunar sample return mission. CHINA NATIONAL SPACE ADMINISTRATION

Still, even if you had a honking, million-watt narrowband transmitter broadcasting in all directions and located one-tenth of a light-year away, contemporary SETI experiments wouldn't be able to find it. And that's not even as far as Alpha Centauri!

On the other hand, suppose that megawatt transmitter were mounted on an antenna the size of the Arecibo radio telescope in Puerto Rico, which is 1,000 feet (300 meters) in diameter. Focused in our direction, the intensity of the signal would be increased by more than 10 million times. It would be detectable by our current SETI experiments at a range of nearly 300 light-years. There are about a million star systems closer than that.

It comes down to this: SETI scientists are betting that extraterrestrials are either focusing a signal in our direction or wield transmitters far more powerful than our own.

Seth Shostak
SETI Institute
Mountain View, California

Q: WHAT WOULD HAPPEN IF THE MOON WERE SUDDENLY TURNED SO ITS FARSIDE NOW FACED EARTH?

Dave Gottschalk
Crystal Lake, Illinois

A: The Moon keeps its familiar face pointed toward Earth, but there are two stable positions. It also would be stable if its farside faced our planet. At the present time, there are small impacts that must kick the Moon away from perfect orientation. When that happens, it oscillates about its stable orientation in two ways. The Moon can rock back and forth in the east-west direction. This oscillation takes 1,056 days, or 2.9 years. The lunar poles also can become unstable, causing a 75-year wobble. Earth's poles experience a similar effect called Chandler wobble.

The Moon also experiences tidal distortion from Earth's gravitational pull.

Giant basin-forming impacts could have reoriented the Moon early in its lifetime. Such large impacts would have left the Moon rocking by large amounts until the friction damped the motion. These basin-forming impacts happened when the Moon was much closer to Earth.

The most obvious effect of a 180° rotation would be to face the brighter farside highlands toward Earth at Full Moon, causing it to appear about 30 percent brighter. It is unclear how much this would affect the tendency of dogs to howl at the

The Moon owes its black sky to not having an atmosphere that can scatter photons. The sky is so dark that an astronaut hiding from sunlight in a shadow would be able to see the stars. NASA

Moon, etc. Would this have an appreciable effect on Earth's energy budget? I can't say precisely, but the Full Moon is about two-millionths as bright as the Sun and is only visible during part of the month, so the effect would certainly be less than one millionth of the Sun's brightness. The Moon is not, contrary to some reports, a significant source of lighting (about one lux, vs. 50 to 500 lux for indoor lighting), but it's better than nothing during harvest time.

Gregory Neumann
Goddard Space Flight Center
Greenbelt, Maryland

Q: ASTRONOMERS KNOW THE FATE OF SUN-LIKE AND MASSIVE STARS, BUT WHAT ABOUT THE MAJORITY OF STARS — THE M-CLASS RED DWARFS? WILL THEY ALSO BECOME GIANTS OR JUST FLICKER OUT?

Mike Hardin
San Antonio

A: The lifetime of a star is the period during which it stably fuses hydrogen in its core and aligns with the main sequence on color-magnitude diagrams. The length of this period depends on a star's hydrogen supply and the rate at which hydrogen is turned into helium via fusion.

Like gas-guzzling SUVs, more massive stars may contain more hydrogen fuel, but they use it up much faster because they are more luminous (a star's luminosity is equal to the rate of fusion energy production).

As a result, the lifetimes of more massive stars are shorter. While astronomers expect our Sun to have a full hydrogen-fusing lifespan of about 10 billion years, a star 10 times as massive as the Sun lasts only about 30 million years, or 300 times shorter — a cosmic blink of an eye.

So, do M dwarfs, as small as one-tenth the mass of the Sun, last 300 times longer, or 3 trillion years? In fact, they probably live even longer than that. Stars like the Sun only fuse the hydrogen present in their cores — about 10 percent of the total supply — before they evolve into red giant stars.

M dwarfs, which have dense interiors, transfer heat from core to surface through convection, the same process that causes a boiling pot of water to roil. The mixing motion of convection allows nearly all of the hydrogen in an M dwarf to make it through the core and fuse into helium, effectively doubling its lifetime. According to the calculations, the smallest-mass star, about 8 percent the mass of the Sun, could last over 10 trillion years, or 1,000 times longer than the current age of the universe.

Even when they deplete their hydrogen, most M dwarfs still won't become red giants; instead, they'll evolve into blue dwarfs. All fusing stars become more luminous over time as the depletion of hydrogen speeds up their nuclear reactions. A star adjusts to this increased power output by either boosting its surface area (becoming a giant) or getting hotter (turning blue). M dwarfs take the latter route, or rather they will — several trillion years from now.

By that time, the Milky Way will have ceased star production, and what remains will be a large population of low-mass blue stars and a menagerie of fading compact objects: brown dwarfs, white dwarfs, and neutron stars. Eventually, even M dwarfs will run out of hydrogen fuel and become helium white dwarfs, slowly cooling with time. The universe will become dark, except for the rare brilliant supernova driven by a white dwarf-white dwarf collision. Low-mass M dwarfs are likely to be the last representatives of the universe's current stellarifous era.

Adam Burgasser
University of California, San Diego

Q: HOW IS IT THAT IN SPACE, DESPITE THE SUN'S PRESENCE, THE SURROUNDINGS LOOK BLACK? APOLLO PHOTOS SHOW A BLACK SKY, EVEN WITH STRONG SUNLIGHT ON THE SURFACE.

Percival Hanley
Basseterre, St. Kitts, West Indies

A: The answer to this question can be summed up in two words: no atmosphere.

Planetary atmospheres cause bright light to scatter. Atoms, molecules, and dust interact with photons, causing them to diffuse through increasingly dense layers as they near a body's surface. On Earth, our atmosphere preferentially scatters blue light, so the daytime sky appears blue. And although Mars has an atmosphere that is some 100 times thinner than our planet's, there's still enough of it to cause the sky to appear a deep grayish blue, and if martian dust is whipped up by the tenuous surface winds, the sky turns a salmon pink.

On the Moon, there is no atmosphere, so there's nothing to scatter photons, even from a brilliant source like the Sun. In fact, if you could find a deep enough shadow that shields your eyes from direct sunlight as well as light reflected off the surrounding terrain, you'd be able to see the stars!

There's another factor that plays into images taken by the Apollo astronauts from the Moon's surface, and that is the limited dynamic range of the film used to record their surface activities. The sunlight is so overwhelmingly bright that, in order to record highlights, the shadows and sky had to be heavily underexposed.

Geoff Chester
U.S. Naval Observatory
Washington, D.C.

Send us your questions

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

COSMIC**IMAGING**

BY ADAM BLOCK

When rejection is good, part 1

The genesis for this column comes from my experience with image processing. When I began digital photography in the early 1990s, most amateurs would take pictures totaling a few minutes of exposure and add them together. These gray-scale images far exceeded what could be accomplished with film in the same period of time.

More experienced imagers combined RGB-filtered images. However, the exposure times and number of frames collected remained small. Interestingly, imagers often would buy larger instruments and more sensitive cameras before increasing the exposure duration and number.

Later, the seemingly esoteric practices of image processing, done by professional astronomers, trickled down to the amateur realm through the inclusion of utilities in popular software. One such area is the statistical analysis of data, which permits the identification and management of unwanted sources of noise and signals. Before imaging software included these tools, it was extremely difficult to eliminate satellite trails, defects on chips, and cosmic rays.

When I accommodated visitors at Kitt Peak National Observatory as part of an observing program I developed that ran from 1996 to 2005, I spent countless hours manually removing these "vermin" from pictures while guests often fell asleep behind me. After all, guests expected to go home with pretty pictures by the end of a night! As I used Photoshop's "Clone" tool (and later the "Healing" brush), visitors often would be concerned that I might erase a galaxy rather than a cosmic ray.

Nowadays, guests who visit me at the Mount Lemmon SkyCenter have a much better experience joining me in the processing of images. The tedium of removing cosmic rays is a thing of the past. In order to understand how this happened, you must understand the nature of light and the power of statistics. Every time we take an exposure, each pixel of the detector is making a measurement. When I take a 20-minute exposure, the picture that results has a single value for each pixel.

Because of the particle nature of light, the number of photons a CCD chip detects fluctuates with each exposure. If the average intensity of a star on a specific pixel is 1,000 counts (brightness units), then in the first exposure I might measure 943 counts, and in the next exposure it may be 1,078 counts. So, if I take enough exposures and average them together, the resulting value will be a good approximation of the intensity. Unfortunately, we never know what this average value should be beforehand. That's why we need to make many measurements to find the average (or mean) value.

Image #1 graphically shows an analog to these fluctuations. In Photoshop, I took a simple column of six pixels that display a low-contrast pattern (a mere two shades of gray) and applied "Add Noise" to imitate fluctuations. After generating 11 pseudo-measurements, I then created the column labeled "Average." Note that you would be hard-pressed to identify the expected pattern from any individual row. Only after averaging the results does it start to approximate the "Ideal" form.

Image #2 shows a real-world example. The left side is a single measurement, and the right half is the average of 20 values at each pixel for a strange planetary nebula called WeBo 1. Closer inspection shows some bright blips in the single exposure that are not in the average image. Most of these are cosmic rays, which represent values we do not want to include when calculating the mean of a set of measurements.

In Image #3, a cosmic ray (a white pixel) was part of the fifth measurement. It contaminated the resulting mean value for that pixel, and it degrades the image quality. What we want to do is identify such outlying values and not use them when calculating the mean.

This means that for the 20 values measured at a particular pixel in the WeBo 1 image, if a cosmic ray activated that pixel, we should reject that value and calculate the mean from the remaining 19 values. This greatly improves the image quality and eliminates transient signals in our images.

In my next column, we will look at how to measure the average amount of fluctuation and then identify these outlying values.

FROM OUR INBOX

Corrections

On p. 55 of the September issue, the upper-right photo was captioned as Ireland. It was, instead, London. — ***Astronomy* Editors**

On p. 16 of the December issue, under "Cosmic World," Brandon Smith was listed as a congressman from Kentucky. He is actually a Kentucky state senator. — ***Astronomy* Editors**

We welcome your comments at Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

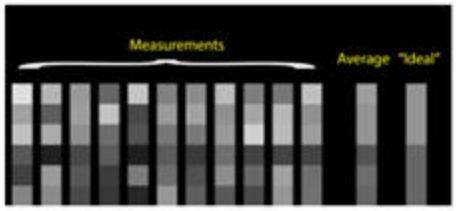


Image #1. Each column is a picture of a low-contrast gray object. Because of the random fluctuations in values, we can't discern the pattern until we know the average value. The author has shown the ideal value in the right column.

ALL IMAGES: ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

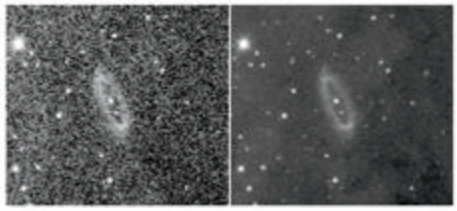


Image #2. The left image is a single 30-minute exposure of planetary nebula WeBo 1 through a Hydrogen-alpha filter. The right image is the average of 20 exposures (for the mean value at each pixel). Note how it reveals more of the galaxy's structures.

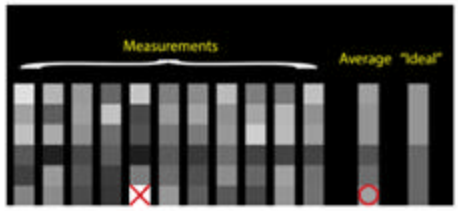


Image #3. Identical to the first image, but here a white square, representing a cosmic-ray strike, degrades the image quality by affecting the mean value at that pixel. To view an online version of WeBo 1, go to http://skycenter.arizona.edu/gallery/nebulae/WeBo1.

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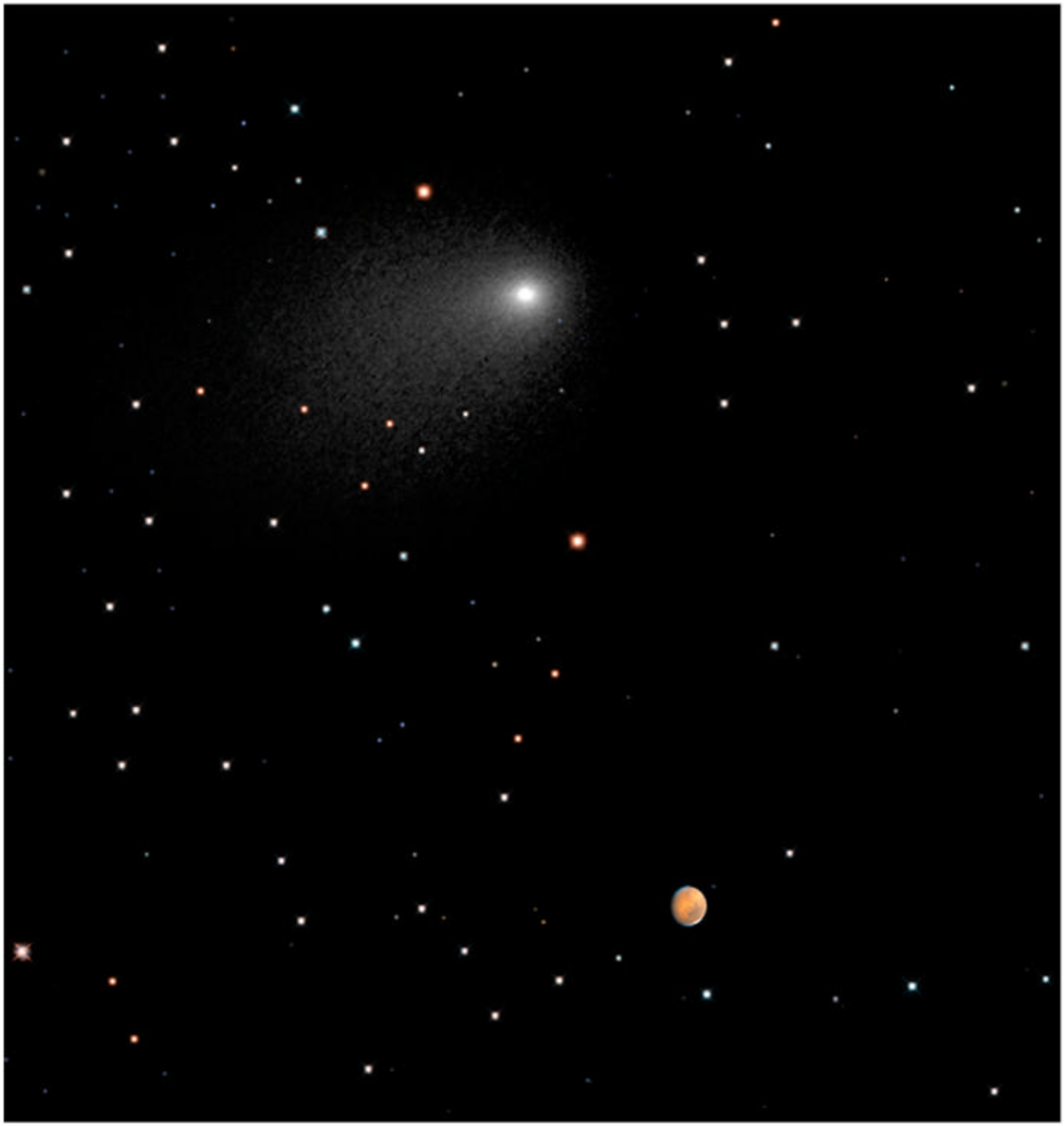

NASA/ESA/J.-Y. LI (PSI)/C.M. LISSE (JHUAPL)/THE HUBBLE HERITAGE TEAM (STScI/AURA)

Hubble captures a unique moment

This past autumn, a unique event in solar system history took place when Comet Siding Spring (C/2013 A1) passed within about 87,000 miles (140,000 kilometers) of Mars. Such a close encounter had not been observed before, and it was reminiscent of when, in 1994, the 21 pieces of Comet Shoemaker-Levy 9's nucleus bombarded Jupiter's cloud tops.

The Hubble Space Telescope captured a splendid composite image of Comet Siding Spring and Mars on October 19, 2014, when the two were approximately 149 million miles (240 million km) from Earth.

Astronomers assembled the two images to accurately depict the angular separation between Mars and the comet at closest approach.

ONE HALF OF THIS IMAGE WAS TAKEN WITH A $2,499 ESPRIT

THE OTHER WAS TAKEN WITH A SCOPE THAT COST TWICE AS MUCH

Actually, the other telescope cost **more** than twice as much as the Esprit, but that's not really the point. The point is, do you see twice as much performance on one side of the page than the other? Take a close look. Are the stars twice as pinpoint? Is the color doubly corrected?

We don't think so.

If you don't think so either, perhaps you should consider purchasing a Sky-Watcher Esprit triplet. At Sky-Watcher USA we pride ourselves on offering products with world-class performance at affordable prices. Because we know there are other things you could be spending that money on. Like a mount. Or a camera. Or even a really, really sweet monster flat-screen television, just for fun.

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Product shown with optional accessories. OTA and camera not included.

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CELESTRON

VENTURE INTO DEEP SPACE

Rowe-Ackermann Schmidt Astrograph

Capturing impressive deep-sky astroimages is easier than ever with Celestron's new Rowe-Ackermann Schmidt Astrograph, the perfect companion to today's top DSLR or astronomical CCD cameras. This fast, wide-field f/2.2 system helps you create better-looking astroimages in a fraction of the time. The 70 mm optimized image circle accommodates even the largest CCD chips for pinpoint stars all the way to the edge of the sensor.

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MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

June 2015: Venus reaches its peak

Few night-sky scenes can rival the proximity of two bright planets. And June brings one to remember when Venus encounters Jupiter in the northwestern sky after sunset.

Venus, the brighter of the two, has adorned the evening sky since the start of 2015. It has been pulling away from the Sun ever since and, on June 6, reaches greatest elongation. It then lies 45° east of our star and appears 20° above the horizon at the end of twilight. Venus continues to brighten all month, however, climbing from magnitude –4.4 to –4.6.

As Venus' orbital motion carries it closer to Earth, the inner planet grows larger while its phase diminishes. These changes show up through any telescope. If you target the world June 1, you'll see a 22"-diameter disk that's a touch over half-lit. By the 30th, Venus appears 32" across and barely one-third lit.

Although Venus gleams about 10 times brighter than **Jupiter**, the solar system's largest planet outshines every star. You can find Jupiter to Venus' upper right. About 20° separate the two June 1, but the gap closes significantly as the month progresses. On the 30th, the divide has dropped to 0.5° — the Full Moon's apparent diameter. The scene takes on added allure the evenings of June 20 and 21 when the waxing crescent Moon slides by.

If you compare the positions of Venus and Jupiter to the horizon each night, you'd think that Jupiter is the one making the big move. But relative to the background stars, which slip lower in the west each evening, Venus is the one on the march. It travels from eastern Gemini across Cancer and into western Leo during June. In contrast, Jupiter drifts slowly from eastern Cancer to just across the border into Leo.

Jupiter is always worth a look through a telescope. This month, its 34"-diameter disk should show plenty of detail. Pay particular attention to the alternating series of light zones and darker belts. Also keep an eye on the planet's four bright moons, which change positions from night to night and often hour to hour.

As if Venus and Jupiter weren't enough, the evening sky boasts a third planetary wonder. **Saturn** reached opposition and peak visibility in late May, and June sees the ringed planet high in the eastern sky after darkness falls. It resides among the background stars of eastern Libra, close to that constellation's border with Scorpius. Saturn shines at magnitude 0.1, a full magnitude brighter than the Scorpion's brightest star, Antares, which lies roughly 10° to the planet's southeast.

Don't let the beautiful pair of planets in the northwest keep you from pointing your telescope toward Saturn. The planet's disk measures 18" across at midmonth while the rings span 42" and tilt 24° to our line of sight. The rings' angle makes it relatively easy to see the Cassini Division, the dark gap that separates the outer A ring from the brighter B ring, even through small instruments.

Mercury becomes a morning object during the second half of June. The innermost planet reaches greatest western elongation June 24, when it lies 22° from the Sun and stands nearly 10° high in the east-northeast an hour before sunrise. Mercury then shines at magnitude 0.5 and appears against the Hyades star cluster in Taurus. Through a telescope, the world appears 8" across and about one-third lit.

Mars remains out of sight all month, passing behind the Sun from our point of view June 14. It will return to view before dawn in August.

The starry sky

In my early days in the planetarium profession, I often wowed audiences by showing them a gorgeous image of the galaxy NGC 2997 taken by renowned astrophotographer David Malin. This image helped introduce many astronomy enthusiasts to the spiral's rather inconspicuous host constellation, Antlia the Air Pump.

Antlia appears high in the west after darkness falls these June evenings. It lies immediately south of Hydra the Water Snake, but it is easiest to find by looking approximately midway between Sirius, the night sky's brightest star, and Spica in Virgo. Although Antlia's brightest stars glow only at 4th magnitude, the constellation's roughly triangular shape shows up under a dark sky.

Many constellations bear little resemblance to the object or creature they're named after, and Antlia is no exception. Eighteenth-century French astronomer Nicolas Louis de Lacaille created the constellation to commemorate the air pump's invention a century earlier. He first depicted it as a simple single-cylinder device on a planisphere he created in 1756.

Lacaille originally named the constellation la Machine Pneumatique, but he later changed it to Antlia Pneumatica. Later astronomers shortened it to Antlia.

NGC 2997 is a spiral galaxy located in western Antlia at a distance of roughly 50 million light-years. Glowing at 10th magnitude, it's not hard to spot in a 20-centimeter telescope on a dark night.

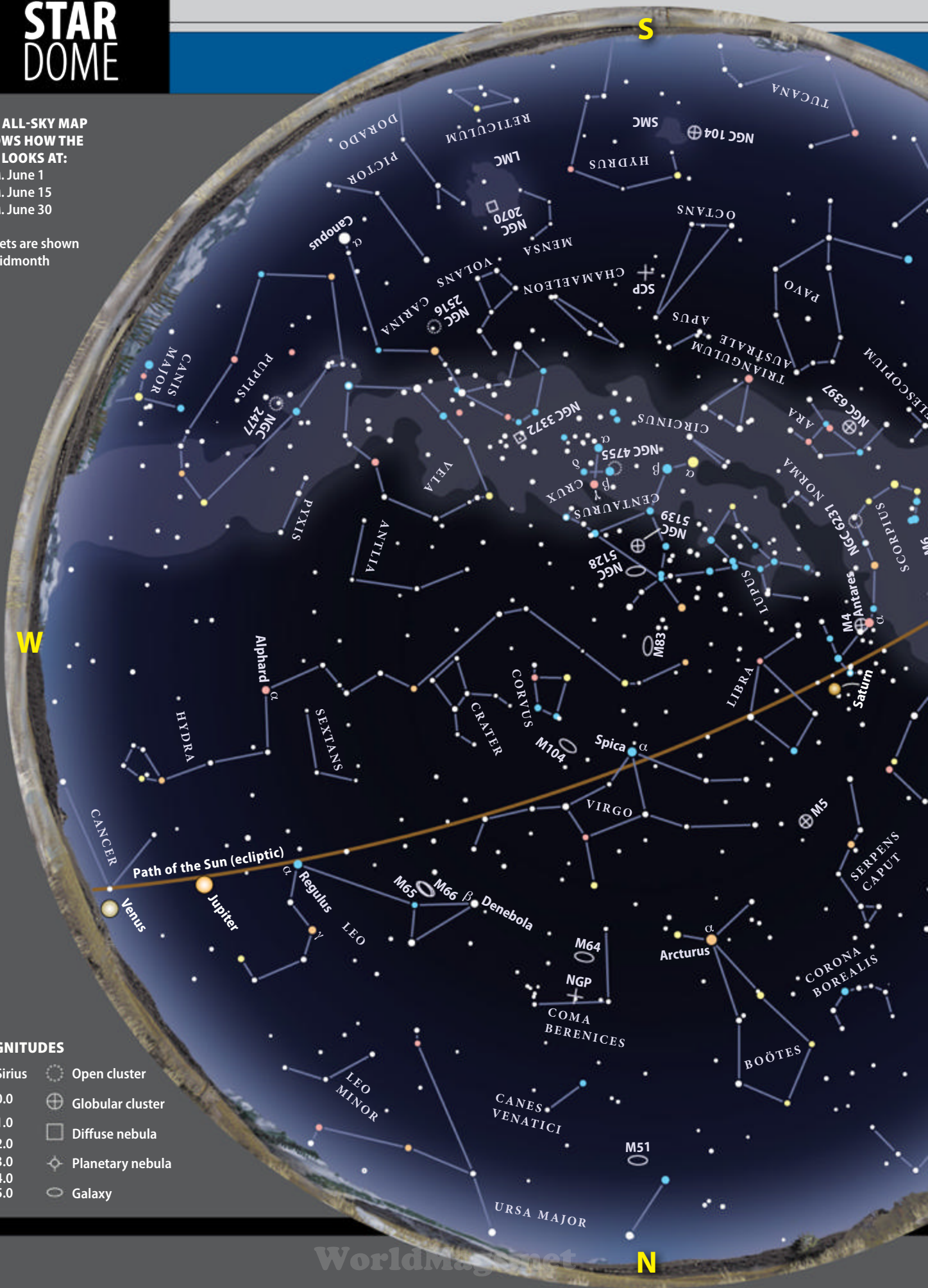
Although several fainter galaxies call Antlia home, I want to highlight two nice double stars. Delta (δ) Antliae has magnitude 5.5 and 9.8 components separated by a relatively easy 11". And Zeta[1] (ζ^1) Ant is the western member of a pair of 6th-magnitude stars near Antlia's western border with Pyxis. Focus in on Zeta[1] and you'll discover it is an attractive double whose stars glow at magnitude 6.2 and 6.8 across a divide of 8".

No matter how hard you try, you won't find stars labeled Beta (β) or Gamma (γ) in this constellation. When the International Astronomical Union defined the constellation borders in 1928, Beta and Gamma ended up in neighboring Hydra. Although Delta, also cataloged as SAO 178771, lurks just over the border, Beta (SAO 202901) lies several degrees inside Hydra.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
9 P.M. June 1
8 P.M. June 15
7 P.M. June 30

Planets are shown at midmonth



MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white without optical aid.

Illustrations by *Astronomy*: Roen Kelly

JUNE 2015

Calendar of events

1 The Moon passes 1.9° north of Saturn, 20h UT

2 Full Moon occurs at 16h19m UT

6 Venus is at greatest eastern elongation (45°), 18h UT

Asteroid Ceres is stationary, 22h UT

9 The Moon passes 3° north of Neptune, 3h UT

Last Quarter Moon occurs at 15h42m UT

10 The Moon is at perigee (369,711 kilometers from Earth), 4h44m UT

11 Mercury is stationary, 20h UT

The Moon passes 0.5° south of Uranus, 20h UT

12 Asteroid Pallas is at opposition, 1h UT

Neptune is stationary, 20h UT

14 Mars is in conjunction with the Sun, 16h UT

15 The Moon passes 0.04° south of Mercury, 2 UT

The Moon passes 1.0° north of Aldebaran, 12h UT

16 New Moon occurs at 14h05m UT

20 The Moon passes 6° south of Venus, 11h UT

21 The Moon passes 5° south of Jupiter, 0h UT

Winter solstice occurs at 16h38m UT

23 The Moon is at apogee (404,132 kilometers from Earth), 17h00m UT

24 Mercury passes 2° north of Aldebaran, 8h UT

First Quarter Moon occurs at 11h03m UT

Mercury is at greatest western elongation (22°), 17h UT

29 The Moon passes 2° north of Saturn, 1h UT